Production Note

ARISTOTLE

ON

YOUTH & OLD AGE, LIFE & DEATH

AND

RESPIRATION

TRANSLATED, WITH INTRODUCTION AND NOTES, BY

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ARISTOTLE ON THE PARTS OF ANIMALS. Translated, with Introduction and Notes, by W. OGLE, M.A., M.D., F.R.C.P.

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PREFACE

THE treatise, of which a translation is contained in the following pages, is represented in all editions of Aristotle's works as consisting of two or more distinct opuscula, but without any perfect agreement among editors as to its precise subdivision. According to Bekker, the first six chapters form a treatise on Life and Death, Youth and Old Age, while according to Weise and the Tauchnitz edition the heading of this part should be only Youth and Old Age. All the remainder is held by Bekker to be a treatise on Respiration, while Weise cuts off the last four chapters and makes them form a separate opusculum on Life and Death. There seems, however, no adequate reason for any subdivision whatsoever of the treatise, and it appears more consistent with its internal structure to regard it as a single work dealing with several closely connected topics. For convenience, however, of reference, Bekker's subdivision and chaptering have been followed in this translation, while at the bottom of each page is given the reference to the page, column, and line of the Berlin edition.

The text of the treatise, which was apparently the last of those written by Aristotle on the phenomena of animal life,[1] is far from being in a satisfactory condition, and it is much to be wished that some competent scholar should undertake its thorough revision. There are numerous obvious verbal errors, for some of which the necessary amendments can be supplied with much confidence, while in other cases it is not difficult to suggest new readings, which, if more uncertain, are yet fairly probable; but there are also no few passages where the corruption has spread more widely, and where a translator must content himself with giving what appears to be the general drift of meaning, while he altogether ignores some unintelligible detail.

The text is also much marred by frequent and annoying repetition, and the idea irresistibly suggests itself that the transcriber had two somewhat different versions before him; and that, instead of simply selecting the better of these, he attempted to combine the two, and did this so unskilfully as to cause much iteration and confusion.

Throughout his task, the translator has had the benefit of frequent and valuable assistance from his friend, Mr. Poste of Oriel College, Oxford, to whom he is glad to have this opportunity of expressing his gratitude.

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[1] 467, b, 8. *De Long. et Brev. Vit.* 6, 8.

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INTRODUCTION

I

LIFE is ascribed by Aristotle to the presence of a soul, of whose activity it is the manifestation. There is a soul in all living things, whether plants or animals, but in different degrees of complexity. In plants it is purely nutritive;[1] in animals, even of the lowest grade, it is at once nutritive and sensory; in higher animals, nutritive, sensory, and locomotive; and, in the highest of all, not only such but also intellectual.

This soul, or vital principle, is not itself corporeal, but yet is inseparable from the body; and the first question that presents itself is, in what region of the body is it located. It is, says Aristotle, to be found to some extent in every part. In plants the phenomena of cuttings and grafts clearly show this to be the case; for each such detached piece can reproduce the entire parent-form. In some of the lower animals, such as centipedes, the fact is also apparent enough; for, if such an animal be cut in two, each part retains sensibility and power of motion.[2] But, as we get higher in the scale of life, this diffusion of the soul to all parts of the body becomes less and less

[1] Aristotle includes reproduction under nutrition. The distinction drawn by him between plants and animals is of course identical with that embodied in the often-quoted formula of Linnæus: 'Vegetalia crescunt et vivunt. Animalia crescunt, vivunt et sentiunt.'

[2] See note 17.

apparent—being still noticeable, however, in such an animal as the tortoise,[1] which shows signs of life even after removal of the heart—and it altogether vanishes in the highest animals, where centralisation has been carried to the utmost extent.

Such an insect as a centipede is, says Aristotle, to be regarded as though it were an aggregate of individuals fused together[2] by growth, and each, of course, with its separate soul. Consequently each segment of a divided centipede can live independently for a space, and would indeed live on indefinitely were it not that it wants the necessary organs of nutrition, such as mouth, stomach, and the rest. Even in such insects, however, there is a certain amount of centralisation. The soul in some centrally placed individual of the aggregate—to carry on the parallel—is more powerful than the souls of the remainder ; and, as we rise from insects higher and higher in the scale of life, its predominance becomes more and more marked, and the other souls more and more subordinate, until finally they are all merged in it.

What part then of the body is it that in the lower animals forms the main seat, and in the higher animals the exclusive seat, of the vital principle or soul? Aristotle adduces many arguments to show that the organ must be somewhere in the central region of the body. This, he says, would be the most advantageous position, for by it the dominating power and the several parts which it governs would be brought into the most convenient relation with each other ; and of all possible courses nature invariably selects that which is most advantageous, a dictum which, if for nature we read God, finds re-expression in the axiom of Leibnitz that of all available plans supreme wisdom combined with equally supreme goodness cannot possibly but select the best.[3] To this *à priori*

[1] 479, a, 5. *De Resp.* 17, 4, and 468, b, 15. *De Juv. et Sen.* 2, 7. Cf. note 139. [2] 468, b, 9. *De Juv. et Sen.* 2, 7.

[3] 'Jam suprema ista sapientia, bonitati non minus infinitæ adjuncta, non

argument he adds others drawn from observation. The body of an animal, he says, consists of three divisions, the head, the thorax, and the abdomen. Now you may cut off the head of a bee or wasp, and the united thorax and abdomen will still retain vitality; and, similarly, you may cut off the abdomen, and this will die while the thorax with the head will remain alive. In each case that extremity which is in conjunction with the thorax is the one that survives, while the part not so conjoined perishes; from which it is clear that it is the central part that determines the survival.[1] Again, when a seed is germinating, it is from the point where the two cotyledons are connected with each other, that is from the most central point, that both root and stem are given off.[2]

Having thus, to his satisfaction, located the soul in the central region of the body, he proceeds to inquire more precisely in what organ of this central region it is placed.

The sensory soul, he says, cannot be elsewhere than in the heart; for all the organs of sense are connected with this heart, while among them there are at any rate two that have no connection with the brain,[3] which is sometimes considered to be the *sensorium commune*.[4] But if the sensory principle be in the heart, there also must be the nutritive principle; for though the soul may be capable of multiplication, as is to be concluded from the phenomena already mentioned of plants and insects, it is indivisible, in the sense that its parts or faculties cannot be dissociated.[5] The soul in each surviving segment of the divided centipede represents not a part of the soul of the undivided parent, but the soul in its integrity.

Of the other arguments advanced by Aristotle, either in this treatise or elsewhere, for the localisation of the soul in the heart, the most notable are that disease of this organ

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potuit non eligere optimum.'—*Tent. Theod.* 8. This is the doctrine ridiculed by Voltaire in his *Candide.*

[1] Cf. note 10. [2] Cf. note 22.

[3] Cf. note 27. [4] Cf. note 29. [5] Cf. note 3.

is more certainly and more rapidly fatal than that of any other;[1] that psychical affections, such as hope and fear, cause commotion not in the brain but in the heart,[2] which they set in violent action; and, chief argument of all, that the heart is the first part that is distinctly formed in the embryo, making its appearance in the chick after three days' incubation, as a red spot—the *punctum saliens* of later writers—which palpitates and moves as though endowed with life.[3]

To those who held with Aristotle, and the physiologists of a long series of centuries after him, that the soul or principle of life was localised in some special and limited portion of the body, this last argument must have seemed irresistible. For the principle to which was due, among other vital activities, the successive development of all the organs of the body, could manifestly not be lodged in any other part than that which preceded the rest in its appearance. The only question, therefore, open to discussion would be as to the part to which this precedence should be ascribed. Had those who were inclined to place the seat of the soul in the brain recognised the primitive groove, which is the first embryonic structure to appear in the fecundated ovum, and known that this was the rudiment of the future brain and spinal cord, they would without doubt have seized on this fact to support their doctrine; but, as things then were, the only possible competitors for the place of precedence were the blood or the heart and vessels in which this is contained. The appearance of the heart is in fact slightly posterior to that of certain vessels, but this was unknown to Aristotle, and is indeed expressly denied by him.[4] There remained then only the heart itself and the blood between which to choose. These are, in fact, formed simultaneously, as Aristotle himself appears in some passages to recognise.[5]

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[1] 667, a, 33. *De Part.* iii. 4, 31.

[2] 666, a, 11. *De Part.* iii. 4, 12.

[3] 561, a, 11. *Hist. An.* vi. 3, 2; and 665, a, 33. *De Part.* iii. 4, 14. See also note 24.

[4] 480, a, 8. *De Resp.* 20, 6

[5] Cf. note 148.

Still, the striking activity of the heart, visibly throbbing in the scarcely formed embryo, as contrasted with the passive character of its contents, and not perhaps impossibly the fact that these contents when first formed are colourless [1] and therefore scarcely to be looked on as true blood, led Aristotle to assign priority to the heart—which is indeed the first organ to enter into functional activity—and to place in this the local habitation of the soul.

Some twenty centuries later our own Harvey, believing equally with Aristotle in the localisation of the soul, and holding, equally with him, that such localisation must of necessity be in the first-formed part of the embryo, held that such primary part was the blood, and that this fluid was therefore the seat of the principle of life. 'There appears at first,' he says, 'a red-coloured pulsating point or vesicle, with lines or canals extending from it containing blood in their interior, and in so far as we are able to perceive from the most careful examination, the blood is produced before the *punctum saliens* is formed, and is further endowed with vital heat before it is put in motion by a pulse,' and 'I hold it as consonant with reason to believe that the blood is prior to its recipient, the thing contained to wit to its container, inasmuch as this is made subservient to that;' [2] and again: 'From this it clearly appears that the blood is the generative part, the fountain of life, the first to live, the last to die, the primary seat of the soul, the element in which, as in a fountain-head, the heat first and most abounds and flourishes.' [3]

Aristotle's localisation of the soul of the higher animals in the heart, and also Harvey's localisation of it in the blood, have long gone to join many another ingenious hypothesis; but in Aristotle's remarks, already cited on an earlier page, as to the multiplicity of life-centres in the lower

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[1] 'For we see, while the chick is in the egg, the heart beating, and it then contains a transparent fluid before any red globules are formed, which fluid we may suppose to be the serum and the lymph.'—*John Hunter's Works*, iii. 66.

[2] Sydenham edit. p. 374. [3] Syd. ed. p. 377.

animals, and their gradual centralisation as one mounts the scale of animal life, is clearly to be recognised the germ of the modern doctrine, according to which every compound organism, however complex its structure, is to be regarded as consisting fundamentally of a number of distinct units, each endowed with its own individual vitality and capable of maintaining its existence independently of its fellows. In the lower forms these units are precisely similar to each other, and the only bond between them is that of simple aggregation; but soon such aggregate becomes an association, in which the units, more or less differentiated in form and function, sacrifice some part of their independence to minister to the common weal. The higher we mount in the scale of life, the greater the differentiation of the units, the more complex their mutual relations, the less prominent their independence, and the more subordinate their separate vitalities to that of the whole of which they are members, until eventually the individualities of the component units are so merged in the individuality of the aggregate organism, that they are apt to be lost sight of to general observation, though it requires but slight attention to show that they are still there.

In those imperfect organisms in which the component units are little differentiated, division is merely loss of size, and the divided parts live as well as before; but, the greater the differentiation and mutual interdependence, the less is such retention of life possible. When, for instance, the units, or groups of units, that in the division of labour have undertaken for the rest the duty of the reduction of the food, are removed or fail to perform their work, the remaining units that have abandoned this office must of necessity succumb. The reason why they do not continue to live is, as Aristotle justly observes [1] of such segments of a divided insect or centipede as are without mouth or

[1] 468, b, 7. *De Juv. et Sen.* 2, 6, and 411, b, 23. *De An.* i. 5, 30.

other such part, that they have not got the organs requisite for their nutrition; were these present they would survive.

If, then, the soul be lodged in the heart, in what shape or condition is it there present? As an immaterial principle or essence, or as an actual substance, or as an essence embodied in some material substratum? The vivifying influence of the sun was of course as conspicuous to the ancients as to ourselves. Every year, as the sun mounted in the heavens, they saw the earth waken from its winter torpor, plants and trees burst into bud and leaf, and the life of animals assume increased energy. As the sun's heat waxed greater, so also did the activity and exuberance of life, again to subside in autumn with the fall of temperature, and to relapse in the cold of winter to its former state of suspended animation. Year after year this striking cycle repeated itself with unbroken continuity. Moreover in the living body of man himself, as of all other mammals and all birds, the most notable feature was its constant heat. The body in life was warm to the touch, and became cold on death. Excessive cold put an end to life, and cold of less intensity brought numbness to the part affected, diminishing its sensibility and power of motion, and generally checking its vital activity. With such phenomena constantly before them, it could not but be that many philosophers should identify the soul with heat, and amongst those who did so was Democritus, whose views we shall have to consider later on. This doctrine, however, did not commend itself to Aristotle. That the soul was actually heat or fire seemed to him impossible; his reason being, if I understand him aright, that, were the soul of fire or of air or of any other homogeneous substance, it must of necessity be itself homogeneous,[1] and not contain, as it did, distinct parts or faculties. The soul, moreover, would be alike, saving in degree, in all living

[1] 411, b. *De An.* i. 5, 22-4

things, whether plants or animals, whereas it differed largely in kind in the different groups.

But though the soul was not itself fire, fire was its necessary agent, being indeed the material substratum in which the soul was incorporate, and without which it could not exist. 'Birth corresponds to the first embodiment of the soul in fire; life to the persistence of this association; death to its dissolution.'[1]

This fire or vital heat, in which the soul was embodied, was not ordinary fire nor ordinary heat, nor any derivative thereof, but something of nobler origin and higher power, akin to, if not identical with, that divine substance of which the sun and heavenly bodies were made; and it was to the presence of this celestial spark, imparted to the germ by the male parent at the time of fecundation, that the heat constantly developed in the heart owed its efficacy, and was enabled to produce results of nutrition and reproduction, that were quite unattainable by the action of terrestrial elements.[2]

That there is some special force—be it called soul, arché, entelechie, vital force, vital principle, or what it may—existing in living beings and in them alone; a force antecedent to their structural development, and that determines this and all their later vital activities, has ever been and still is the creed of some philosophers and physiologists. Those who deny or dispute its existence argue that force has no existence independently of matter, and that consequently the supposed vital force must be something inherent in the constituent material of the living body. But the living body is entirely made up of oxygen, hydrogen, carbon, nitrogen, and other similar elements. The vital force then can be no special force, but must be some force derived from those inorganic elements, manifesting itself in a special way, because the combina-

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[1] 479, a, 29. *De Resp.* 18, 1. Cf. notes 141, 142.
[2] 736, b. *De Gener.* ii. 3, 11-13.

tion of conditions required for its manifestation is only to be found in organic compounds. This argument, says Milne Edwards, whose statement [1] of it is here followed, is unanswerable, if it be once admitted that the living body is in reality entirely made up, as affirmed, of molecules of known and ponderable matter, but falls to the ground if we suppose the presumed vital force to be the property of some more subtle and intangible substance, analogous to that imponderable matter, the existence of which is assumed by physicists, and to which they give the name of ether.

This hypothesis, to which Milne Edwards apparently inclines, though without perfectly distinct acceptation, approximates very closely to Aristotle's doctrine of a soul incorporate in some non-terrestrial substance, akin to, if not identical with, that ethereal element of which he conceives the celestial luminaries to be made.

Before going further in our analysis of Aristotle's doctrine, it will be well to point out that his attribution of natural heat to plants and to cold-blooded animals was a pure assumption, and one for which he advances no scrap of direct evidence.[2] In the higher animals the association of life with heat is obvious, and from this Aristotle inferred without proof the universality of such association. We know nowadays that in all living things, whether plants or animals, a combination of oxygen with carbon occurs in

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[1] The argument, as stated by M. Edwards (*Leçons sur la Phys.* xiv. 261), is as follows: 'Une force n'est rien indépendamment de la matière, elle en est une propriété, et ne saurait exister sans elle. Les principes d'action qui existent dans un corps vivant sont, par conséquent, inhérents à la matière constitutive de ces corps. Or, la matière dont ces corps sont formés provient du règne mineral et y retourne. Il faut donc que les forces en question viennent aussi de la matière non-vivante et, par conséquent, qu'elles soient des forces générales (ou forces inorganiques) non des forces spéciales; seulement, pour se manifester, il faut que cette matière soit placée dans des conditions qui ne se trouvent réunies que chez les composés organisés.'

[2] Menestor is said by Theophrastus (*De Causis Plant.* i. 21, 6) to have found evidence of the heat of certain water-plants in their not being frozen in winter, and of certain trees in the melting away of snow from their leaves.

the tissues, and that this combination must of necessity be accompanied by the disengagement of heat; but this generalisation is one of our own days, and even in the earlier part of the present century we find physiologists of high repute, such as Treviranus, altogether rejecting the idea that plants, reptiles, amphibia, fishes, and invertebrates, when in their usual condition, possess any power of generating heat.[1] There are exceptional occasions when the warmth developed by a plant or a cold-blooded animal may become more or less readily perceptible, as in the spathe of a flowering arum or the body of an incubating serpent; but under ordinary circumstances the heat developed is so slight as to be quite inappreciable without delicate instrumental appliances, and indeed in plants is usually counterbalanced, or overbalanced, by the refrigerating effects of transpiration and the fixation of carbon.

Whether the soul was identical with fire, as Democritus had taught, or whether fire was merely the substratum in which the soul was incorporate and the instrument of its activity, as Aristotle maintained, fire was equally of absolute necessity; for without it life was impossible. But the body was incessantly parting with its heat, as was obvious to sense, and there must clearly be some means of replacing the loss. This replacement was brought about by the food, which after a primary concoction in the stomach passed to the heart and there underwent a second elaboration, accompanied by the development of vital heat.

That the food is the fuel by which the heat of the animal body is maintained is of course true, the greater part of it being used simply for that end; and if Aristotle thought that the production of heat at its expense took place in the heart, we may remember that Lavoisier,

[1] 'Eben so wenig als die Pflanzen besitzen im Allgemeinen die sämmtlichen Thiere, nur die Säugthiere und Vögel ausgenommen, ein Vermögen Wärme zu entwickeln.'—*Biol.* v. 20 (1818).

with his later knowledge of the nature of combustion, not less erroneously located that production in the lungs.

The doctrine that the heart was the source and centre of vital heat, and that this heat was something of nobler quality and greater efficacy than ordinary fire, appears to have been universally accepted as indisputable truth for many centuries after it had been laid down by Aristotle. It was fully held, at one period of his life, by Harvey, who borrows Aristotle's own language to describe the celestial nature of the vital heat,[1] and who in his Prelections, written in 1616, speaks of the heart as the *fons totius caloris* and its *arx et domicilium.* At a later period, however, Harvey changed his views in this matter.[2] He had, as mentioned on an earlier page (p. 5), transferred the seat of the soul from the heart to the blood, and with the soul he naturally also transferred the vital heat with which it was associated; and we now find him maintaining, in contradiction with his former views, that 'the blood, instead of receiving, rather gives heat to the heart, as it does to all parts of the body,' and that 'the blood is the element in which, as in a fountain-head,[3] the heat first and most abounds and flourishes.'

Van Helmont had already in some degree dissented from Aristotle's doctrine, but this later teaching of Harvey appears to have been the first serious departure from it. The doctrine, however, once called in question, its assailants soon became numerous. The existence of any special kind of heat, whether in the heart or elsewhere in the body, was contested, and the vital heat declared to differ in no respect from that which is developed during fermentation, or which can be produced by friction; and while some, as Descartes,[4] attributed it to the former cause, others, as

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1 Harvey's *Exerc. de Gen. An.* 70, and Arist. *De Gen.* ii. 3, 11-13.

2 This change in Harvey's views as to the localisation of vital heat has been noted by Dr. Church in his interesting Harveian Oration for 1895 (p. 30).

3 See passages quoted at p. 5.

4 *Works*, iv. 437 (Cousin's ed.)

Haller,[1] ascribed it to the latter, the particles of the blood being rubbed during its circulation against the walls of the heart and vessels. Descartes, it is true, while he thought that vital heat was no more than ordinary heat, imagined that the fermentation to which it was due occurred within the heart, and so far still held to the Aristotelian doctrine. But this partial adherence ceased to be possible when Borelli, introducing a thermometer into the body of a living stag, showed that the heart was in no degree hotter than any other of the viscera.[2] This experiment, repeated by others with similar results, gave its death-blow to the ancient doctrine, which fell to the ground never to rise again. Some dim vestige of its past existence still, however, apparently lingers in our language, when we speak of men as warm-hearted or the contrary.

But life not only was threatened with extinction from loss of heat, but also was in constant danger from its excess. Very excessive heat was as fatal to both plants and animals as excessive cold ; and that minor excess was also injurious, if not fatal, to animals was shown by the malaise and the fever it produced in them. Now the fire in the heart, fed by fuel from the stomach, was always tending to produce such excess ; and as there was provision for maintaining the fire, so also must there be provision for keeping it in bounds. This provision Aristotle finds in respiration for such animals as have lungs, and for other animals in the bathing of their gills or the general surface of the body in a medium colder than themselves.

He is thus brought to deal with Respiration, and to this he devotes the chief part of his treatise. The exposition of his views and those of his predecessors on this subject, and the fate of their various speculations in later ages, will occupy the remaining sections of this introduction.

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[1] 'Hactenus certe maxime probabile videtur, utique a motu sanguinem incalescere ; etsi nondum constat, quare magis quam aqua, et quare non super certum gradum incalescere possit.'—*El. Phys.* ii. 307.

[2] *De Motu Anim.* (Rome, 1681) ii. 189.

We must first, however, deal with another subject.

It has been seen what were Aristotle's views as to life: it remains to consider what were his notions regarding death. Death he very properly divides into violent and natural; meaning of course by the former not merely death from those coarser external forces to which we usually limit the term 'violence,' but death from disease, or such adventitious cause as is not inherent in the normal constitution of the body; while natural death is that termination which, independently of disease or violence, comes inevitably in due course of time to every living thing.[1] To what is this natural death attributable? In what does its necessity consist, and what is it that prevents a living thing, when it has once come into being, from living on indefinitely?

In answer to this difficult question, modern writers tell us that there is in the body a something, which may be spoken of as life-force or life-material, that is constantly being consumed and as constantly reformed; and that, while in the earlier stages of life the formation is in excess of the consumption, so that at that period accumulation occurs, and while in middle life production and consumption balance each other, in the later period of age expenditure becomes excessive, so that the stock gradually diminishes, shrinking, to borrow a simile from Huxley, like Balzac's *peau de chagrin* with each vital act, until at last it is used up and life comes to an end.[2] This something was held by Aristotle to be vital heat. In youth this was at its maximum, and the mechanism for its regulation being as yet imperfect, inasmuch as the lung had not yet acquired its full development, there was excessive expenditure, as manifested by the energy of growth. In the prime of life, when the organ of regulation had acquired its full power, the expenditure was

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[1] 478, b, 24. *De Resp.* 17, 1.

[2] Bacon, in his *Historia Vitæ et Mortis*, ascribes natural death to the gradual dissipation of the animal or vital spirit to which all the phenomena of life are due; and the purpose of his treatise is to teach physicians by what means the escape of this spirit can be retarded.

brought under control, and growth ceased with the exception of that form of it which consists in reproduction. Heat, however, was still being lost, and by this gradual dissipation the amount remaining in old age became so small that it was comparable to 'a flickering flame, which the slightest casual disturbance would put out.'[1] Such disturbance, moreover, could not but come, inasmuch as the lung had now become hardened by gradual evaporation of its fluid, and so unable adequately to perform its office of heat-regulation.[2]

Such appears to have been Aristotle's explanation of natural or inherent death; and it seemingly implies the belief that, though heat was constantly being developed in the heart, the amount thus produced was always somewhat less than that which was given off, and that the deficiency had to be made good out of the stock with which the organism started originally, that is, from the innate heat in which the soul was incorporate; and that this eventually was so reduced by the constant drafts made on it that it became insufficient to support the soul.

Natural death, then, being inevitable, after what lapse of time does it come? The natural span of life, says Aristotle, differs greatly in length in different species. These differences must depend ultimately upon radical differences in the material constitution and its degree of harmony with the environment.[3] But, nevertheless, there are certain characters that, as a general but by no means universal rule, stand in close connection with specific longevity. As a rule big animals or plants are longer-lived than the smaller kinds; sanguineous animals, or vertebrates, than exsanguineous animals, or invertebrates; and, generally, the more perfect animals than the less perfect; and, lastly, a long gestation period goes, in most cases, with long duration of life.

These views as to specific longevity are in strict ac-

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[1] 479, a, 19. *De Resp.* 17, 7.

[2] Cf. note 35.

[3] 777, b, 7. *De Gen.* iv. 10.

cordance with those of modern physiology. Bulk, degree of organisation, period of gestation are to a great extent correlated; for great size is habitually associated with high organisation, and this with lengthy gestation; and that these three factors should conduce to length of life is not only shown to be probable by the deductive reasonings of philosophical biologists,[1] but is a conclusion supported by the results of actual observation.[2]

II

The external phenomena of human respiration, namely, the alternate inhalation and expulsion of air through the mouth and nostrils, with the accompanying rise and fall of the walls of the thorax, must have been familiar to man from the time when he first appeared on the earth. Nor can we suppose that there ever was a period when the continuance of this respiratory process was not regarded by him as a sure token of life, and its permanent cessation as an equally sure token of death.

But between the familiar recognition of a phenomenon and the first speculation as to its cause and meaning centuries may intervene; and we have no reason to suppose that in all the long ages that preceded the days of the early Greek physicists one single mind was led to investigate the phenomenon in question.

Even when Greek speculation began, although this was strictly confined to the phenomena of Nature, to the exclusion of those other branches of knowledge which were comprised in Greek philosophy at a later period, very few of the physicists, as this first school of philosophers were called, turned their attention to the subject of respiration; which, engaged as their minds were in attempts to fathom the inscrutable mystery of the nature and composition of

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[1] See H. Spencer, *Princ. of Biol.* i. Ch. on Growth, and Ray Lankester, *Comp. Longevity*, pp. 30–60.

[2] See note 81.

the universe, must have seemed to most of them but a trivial and humble subject.

Still, there were some few among them who found time to consider the phenomena in question, at any rate to a certain extent; though we can but suppose, if the scanty accounts of their views that have been preserved fairly represent the results of such consideration, that the time devoted to the problem must have been extremely limited.

It is true that we scarcely know more of the views of these speculators on respiration than has been preserved for us by Aristotle, who was in this matter their antagonist, and that the views and arguments of a writer are rarely put forth in the best and most favourable form by an antagonist, however desirous he may be to do them justice.

Not only, however, was Aristotle manifestly a man of truth, but, prompted apparently by the fear that the strangeness of his predecessors' doctrines might leave his account of them open to suspicion, he protests directly against being supposed to have misrepresented men who were no longer present to defend themselves, and avers that in stating their views he has practically used their own words.

Be this, however, as it may, we have no choice but to accept his account of the matter, and in sketching the ancient theories of respiration we must of necessity take him as our chief guide.

The aspect of respiration to which these earliest writers mainly devoted their attention was the mechanism of the process; to which some further added the question of its universality in the animal kingdom, and some few the purpose to which it was subservient. Strangely enough, as it appears to us, and, indeed, as it appeared to Aristotle, who makes complaint of it, this last question, that of its utility, was one to which scarcely any of them attempted to give an answer. They seem, as a rule, to have been content to regard respiration as no more than an

inseparable accident of life (σύμπτωμα), though a moment's reflection would have shown them, as Aristotle points out, that this position was untenable, and that respiration was absolutely essential to its maintenance. Democritus, it is true, formed an exception to this rule, nor was he the only exception, as will be seen later on; but at present it will be best to confine ourselves to the various views as to the mechanism of respiration, reserving the question of its utility for later consideration.

The earliest philosophers, then, of whose views as to the mechanism of respiration any record has come down to us, are Anaxagoras and his contemporary Diogenes of Apollonia. Aristotle tells us that these philosophers held that all animals respire, and he has preserved for us a scanty account of the mode in which they supposed the process to be carried on in fishes. They imagined that, when a fish discharges water through the gills from the oral cavity, air passes in from the surrounding water so as to fill up the otherwise vacant space in the mouth, and that the air thus abstracted from the water is then inhaled by the animal. Aristotle does not tell us how they accounted for air rather than water passing in through the mouth so as to fill up the vacant space, but we may plausibly suppose that their notion was that, when the water is being expelled through the gills, the fish closes its mouth—as, indeed, is to a great extent the case—but so closes it as to leave apertures large enough to admit the particles of air, but not large enough to allow the passage of water; for Galen who some centuries later also held that water contains air, and that this air is utilised by fishes for respiratory purposes, supposed that in the gills there were minute openings of similarly nicely adjusted calibre.[1]

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[1] 'Earum, quas branchias nuncupamus, constructio ipsis vice pulmonis est; cum enim crebris ac tenuibus foraminibus sint branchiæ hæ interceptæ, aeri quidem et vapori perviis, subtilioribus quam pro mole aquæ, hanc quidem extra repellunt, illa autem prompte intromittunt.'—Galen, *De Usu Part.* vi. 9.

That ordinary water does in fact contain air, and that this air serves for the respiration of fishes, we now know to be perfectly true. But it was not for very many centuries after the time of Anaxagoras or of Galen that the fact was established.[1] And in Aristotle's days the objection made by him [2] that if there were air in water it would of necessity rise to the surface and escape must have seemed quite unanswerable.

'It had been noticed by divers authors,' says Boyle,[3] who, however, does not apparently accept the statement as certainly true, 'that fishes soon die in ponds and glasses quite filled with water, if the one be so frozen over and the other so closely stopped that the fishes cannot enjoy the benefit of the air;' but this clearly pointed rather to the necessity of the air outside the water than to the necessity of air in the water itself; and, whatever suspicions may have been entertained from more or less imperfect observations, it was not until Jean Bernoulli,[4] writing in 1690, and following out the previous experiments and observations of Boyle [5] and

[1] In the spurious Hippocratean treatise *De Flatibus* (ch. v.) is the following passage: 'Moreover, that the sea is not entirely void of air is manifest. For such creatures as swim could not possibly live if they had no supply of air. And how can they be supplied except by means of the water, and by drawing air from it?'

[2] 443, a, 4. *De Sensu et Sensili*, 5, 2.

[3] Boyle's *Works*, i. 109.

[4] 'Videmus si aqua vel alius liquor super igne coquatur bullulas excitari, manifesto certe aeris intro latentis indicio, qui ope ignis dilatatur, omniaque vincula quibus retinebatur solvit, et ob levitatem ad superficiem usque fertur, ubi tales bullulas format; hinc fit ut pisces in aqua quæ semel ebulliit vivere non possint, ob defectum nempe aeris qui in ebullitione omnis exhalavit; aerem enim et pisces haurire æque necesse est ac cætera animalia. In hunc finem eorum branchiæ conditæ sunt, ut illarum ope aerem, qui ad vitam sustinendam necessarius est, ab aqua secernant, ut de hac re recte sensit Cl. Majowius. Similiter liquoribus aerem inesse experimenta Boyliana confirmant; si enim in vase recipiente liquor aliquis includatur, ex quo deinde ope antliæ pneumaticæ aer extrahatur, statim videbimus innumeras bullullas (sicut in aquæ ebullitione) ex liquore prorumpere.'—J. Bernoulli, *Dissert. de Effervescentia*, ch. xiv.

[5] Boyle (*Phil. Tr.* 1670, and *Works*, iii. 361), after showing that there was 'air latitant in water,' and even attempting to determine its amount, had

Mayow, showed that bubbles of air are given off from water when it is heated over the fire, and that fishes are unable to exist in water that has been boiled, and thereby altogether freed from its contained air, that either the presence of air in water or its utilisation by fishes can be said to have been definitely established, or even to have had the support of any very serious argument. Aristotle, then, was perfectly justified in rejecting as he did the notion that fishes breathe air contained in water as a baseless fancy. He had, however, other weighty arguments to urge against Anaxagoras and Diogenes ; and of these the most telling, in the then state of knowledge, must have been that, if a fish inspires air, it must give this out again in expiration, and that in that case bubbles should be visible when a fish is kept under water, as is the case when a tortoise is so treated, but that nothing of the kind can be detected on experiment.[1] He asks further—and not without pertinence—seeing that, according to Mr. Lewes,[2] even in these days it is not easy to give a thoroughly satisfactory answer to the question—how comes it about, if a fish breathes air, that, when it is taken from the water and put in the air itself, it dies with every appearance of suffocation ; for, says he, the answer of Diogenes that it dies under such circumstances because it has too much air is foolish, seeing that no other animal that breathes air is ever injured by excess of it. The difficulty propounded by Aristotle is a real difficulty, and, as already mentioned, is held by some modern writers to remain as yet unsolved. There are, however, experiments that appear to supply a fairly adequate explanation. For Spallanzani showed

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further propounded the 'quære : whether in common water there may not be concealed air enough to be of use to such cold animals as fishes ; and whether it may be separable from the water that strains through their gills.'

[1] It was by observing that bubbles of air are given off from the stigmata of insects when kept under water that Malpighi demonstrated the respiratory function of their tracheal system. 'Immersis bombycibus præcipue in ardente aqua multum aeris sub bullarum specie ascendit' (*De Bombyc.* p. 13).

[2] Lewes' *Aristotle*, p. 176.

long ago that the gills of a fish act in air no less than in water; and more recently Flourens and Bert have shown that the reason why such action in the air is in most cases insufficient for the maintenance of life is to be found in the collapse of the gills when no longer floating in water of practically the same density as themselves, and the consequent enormous reduction of their exposed and acting surface.

The next philosopher, so far as is known, to handle the mechanism of respiration was Empedocles. This writer unfortunately chose to clothe his utterances in the garb of sonorous but very obscure verse, with the result, possibly with the intention, that, while the general outlines of his conceptions are fairly displayed, all detail is concealed from view. The twenty-five lines in which he dealt with respiration have been preserved by Aristotle, and are interpreted by him as follows: 'There are certain vessels which contain blood, but not in such amount as to fill them. These vessels communicate with the external air by pores, which are too small to admit the particles of blood, but large enough to give passage to those of air.[1] Now it is the nature of blood to move backwards and forwards, and, when it moves backwards, the air flows in through the pores and inspiration occurs, but when it moves forwards the air is driven out, and expiration is produced.' Aristotle, as his criticisms show, supposes Empedocles to have been speaking of respiration through the nostrils, and such is by far the most probable explanation.[2] But it is the belief of some authorities, and not perhaps altogether impossible, that in this Aristotle is mistaken, and that Empedocles was in reality speaking of a supposed respiration by the general cutaneous surface; and, supposing

[1] Much in the same way Aristotle supposed that the sweat was discharged on the surface by passages which were continuations of the blood-vessels, but were too narrow to give passage to the blood itself. Cf. 668, b, 3. *De Part.* iii. 5, 13. It was indeed by the existence of such pores of various calibre in connection with the blood-vessels that all secretion was explained.

[2] Cf. note 66.

this to be the case, the conjecture may be hazarded that the terminal pores of the vessels, which alternately admit and discharge air with the ebb and flow of the blood-tide, were the orifices of the sweat-glands, visible at times to the naked eye in the palms of the hands, where they are both exceptionally numerous and exceptionally large. On this supposition there would be a curious kind of agreement between the teaching of Empedocles and that of modern physiology; for that there is a general cutaneous respiration is undoubted, and it is probable that the orifices of the sweat-glands are the main channels through which the gaseous exchange between blood and air is brought about. Such agreement, however, supposing it to exist, would of course be merely accidental, and there can be no doubt that the speculations of Empedocles as to respiration were no more than speculations, and stood on no basis of observed fact or of anatomical investigation.

There remains but one other pre-Aristotelian attempt to explain the respiratory mechanism, but this one is, for our present purpose, the most important of all; for it is that of Plato, who, as Galen[1] tells us, borrowed his physiology from Hippocrates, so that this explanation of the process must be taken to represent the views of the foremost minds at the time when Aristotle took the subject in hand, and so, by giving the point from which he started, enables us to measure any advance he may have made.

The account, then, of respiration as given by Plato in the 'Timæus,'[2] and as summarised fairly by Aristotle, is as follows: 'When the hot air is discharged by the mouth, the surrounding air is thrust forwards by it, and being carried on by the impulse is made to pass through the porous surface of the body, until it occupies the selfsame space as that from which the hot air had issued, the

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[1] Plato 'cum Hippocratis imitator, si quis alius unquam, fuerit, et ab illo dogmata mutuatus sit maxima.'—*De Usu Part.* i. 8.

[2] Cf. note 56.

replacement being determined by the impossibility of a vacuum; and this air in its turn, when it has become heated, passes out again by the same channels as gave it admission, and, impinging on the air that was previously discharged in a hot condition through the mouth, drives this back again through that orifice to the interior space, and thus a continuous alternation of inspiration and expiration is kept up.'

This strange attempt to account for the visible phenomena of respiration manifestly can have had no pretence of being based on observed facts or on anatomical structure. It was a mere creation of the imagination, and is properly stigmatised by Aristotle as a baseless fiction. Strange, however, as the account is, and curious as is the light it throws on what was held to be adequate explanation of natural phenomena in the pre-Aristotelian period, it is perhaps no less strange and curious to find its ghost still walking the earth as late as in the seventeenth century. At that period it had long been thoroughly recognised that the expansion of the thoracic cavity during inspiration was due to muscular action, and notably to the action of the diaphragm, and neither, as Plato had supposed, to the pressure of incoming air, nor, as Aristotle supposed, to heat; but it was still a matter of dispute what caused the air to enter the expanded cavity, and whether the lungs were active or passive in the process. To this question, says Boyle,[1] writing in 1660, 'some of the best modern philosophers answer, that by dilatation of the chest the contiguous air is thrust away, and that pressing upon the next air to it, and so inwards, the propulsion is continued until the air is driven into the lungs and so dilates them.' To this view, as Boyle goes on to state, it was objected by Bartholin that, if a large glass vessel be taken with a narrow neck, a man, on applying his mouth to the orifice, can suck in air from the vessel, though clearly its walls must prevent

[1] Boyle's *Works*, i. 100.

all pressure from without. One would have supposed that this objection would at once have put an end to the supposed explanation; but ghosts are hard to lay, and it was answered to Bartholin's objections, as we are told by John Mayow,[1] that, though air is unable to pass through glass, yet there may be some more subtle matter that can do so, and that it may be that this matter, propelled by the compressed air without, passes through the walls of the vessel and is driven into the thorax. But if this be so, says Mayow, how comes it about that if a bird or other animal be shut in a glass vessel, and the air be extracted by the then recently invented air-pump,[2] the animal is unable to breathe, although the glass walls form no impediment to the passage of the particles required for respiration? This seems at last to have administered an effectual quietus; at any rate I have been unable to find any further appearance of the 'Timæus' doctrine in later writers.

Such, then, were the notions, so far as they have come down to us, entertained by Aristotle's predecessors in regard to the mechanism of respiration; it remains to consider what were their views as to its utility. Very few of them, says Aristotle, troubled themselves about this. They looked on the process as something incidentally associated with life but as in no way essential to its maintenance. There were, however, some exceptions. Thus there is a

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[1] 'Alii vero existimant, aerem circumambientem proximum sibi vicissim propellere, et ita continuari propulsionem, ut aer tandem ori vicinior in pulmones impellatur.' But he says, 'certo experimento constat posse aerem e vitro satis amplo, cum tenui tamen collo, quamquam naribus arcte obturatis, per os hauriri et inspirari. Enimvero in hoc casu propulsio illa per vitrum ori, uti supponimus, adaptatum continuari non potest. Contra allatum experimentum nonnulli respondent, subtiliorem quandam materiam, ab aere compresso propulsam, vitrum permeare et in thoracem impelli. At qui fit ergo, quod animal quodvis, veluti avis, vitro inclusa, ex quo aer postea extrahitur, respirare non possit, si particulæ respirationi idoneæ vitrum illud etiamnum pertranseant?'—Mayow, *De Respiratione* (Oxon. 1669), p. 3.

[2] The first air-pump was made by Otto von Guericke and exhibited by him at Ratisbon in 1654. Improvements were made in it by Boyle.

passage in the 'De Partibus'[1] from which it appears that there were among Aristotle's predecessors or contemporaries some who held that it was to respiration that the action of the heart was due. What was their precise meaning we can but conjecture. The action of the heart is undoubtedly, in a sense, due to respiration, for if this latter process be stopped, as when an animal is strangled, the blood is unable to pass through the lungs, and this arrest of the pulmonary circulation acts backwards upon the heart and soon brings its motion also to an end. But it is scarcely necessary to say that this cannot possibly have been the meaning of those who, in the days of Aristotle, attributed the heart's action to respiration. It must have been to the mechanical process of respiration, to the alternate expansion and contraction of thorax and lung, and not to the utterly unsuspected chemical changes, that they attributed its influence upon the heart; and the view is therefore worth a passing notice, as being the starting-point of a similar doctrine held by certain iatro-mechanical physiologists in the seventeenth century, when Hook,[2] by one of those noble and decisive experiments that from time to time clear away the mists from the path of science, gave it its death-blow. He contrived an arrangement by which a constant current of air was kept passing through the lungs of a dog without any motion occurring either in lung or thorax, and showed that under such circumstances life was maintained, and the action of the heart continued as before without check or hindrance; so that the heart's action was in no way dependent upon the lungs' motion.

We have next to consider the views of Democritus, who is the only philosopher mentioned by Aristotle by name, as having attributed any use in the animal economy to respiration.

According, then, to Democritus, the universe consists of

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[1] 'It has been stated, but incorrectly, that it is to the lung that the throbbing of the heart is due.'—669, a, 18. *De Part.* iii. 6, 5.

[2] *Phil. Trans.* 1667, *Abridgement*, i. 194.

plenum and vacuum, or, in other words, of matter and empty space. Besides these there is nothing else, nor does soul or mind form an exception. Space is unbounded, infinite; matter is reducible to an infinity of indivisible particles or atoms, that present endless variety of form and size, though they are all precisely alike in substance. All things are aggregates of these atoms, and, though such aggregates may break up, and their constituent atoms enter into new combinations, and though these changes may go on in endless succession, yet the atoms themselves remain unchanged; they are uncreated and imperishable. The differences, then, between substances—mind and soul included—depend on differences of their constituent atoms, and these, as already stated, are differences of form and size, and, it may be added, of position. Now the soul is identical with fire, as is indicated by the palpable coincidence of life with heat; and as the soul is the cause of all vital motion, thought itself being a kind of motion, the atoms that constitute the soul or fire must be those whose form and size are most suitable for rapid motion. Such are the finest spherical atoms. The soul, then, that is the animating principle which is the source of vital heat and of all vital activities, is made of these; and these fine spherical atoms are diffused throughout the body, alternating with the grosser and less mobile atoms that constitute its bulk. These spherical or soul atoms, in virtue of their essential mobility, and in consequence of the pressure of the environing air, are always escaping from the body. The escape of a certain small proportion, if unreplaced, causes sleep; of more, causes swooning or apparent death; of still more, causes actual death; and, as the atoms are always escaping, death would soon ensue, were it not that the loss is constantly replaced by new spherical atoms inhaled with the air from outside. For the air is charged with such mobile spheroids, aggregates of them being visible as dancing motes in the sunbeam. Inspiration, moreover, not only thus replaces the lost soul-atoms, but

hinders their ready escape; for the inhaled air counteracts by its opposing action the pressure of the air without.[1]

This doctrine of Democritus, as to the replacement of soul-atoms by inspiration, would appear from a fragment preserved in the 'De Anima' (i. 5, 13) to have been to a certain extent[2] anticipated by the author of the so-called Orphic poems, when he wrote that 'the soul, borne by the winds, enters from the universe into animals during inspiration;' and may also be regarded as the lineal predecessor of the doctrine of the obscure vitalists of later ages, who even up to the time of Haller were teaching that the inspired air contains a number of active, spirituous, and ethereal particles, which pass from the lungs to the heart and arteries 'inque his organis in spiritum vitalem formatur, in reticulo vero mirabili cerebri in animalem spiritum abeat. Neque inter nuperos desunt, qui hanc animalium spirituum ex aere generationem tuentur.'[3]

Limiting our view to the physiological aspect of his doctrines, we see that Democritus assigned to respiration the all-important office of maintaining the heat of the body, replacing by a continuously fresh supply that which was being as continuously given off from the surface; and this fresh supply he supposed to be contained, already as heat, in the inspired air.

There were, however, others whose names have unfortunately not been preserved for us by Aristotle, but among whom was not impossibly to be reckoned Hippocrates,[4] who, while they agreed with Democritus that the end of respiration was the maintenance of heat, parted company from him when he said that this heat was introduced as such by inspiration, and held that the

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[1] See, for a fuller exposition of the doctrines of Democritus, Zeller, *Pre-Socratic Phil.* vol. ii.

[2] Asclepiades also, according to Galen, ascribed to respiration 'animæ ipsius generatio;' while Protagoras followed his master Democritus in attributing to it not the 'generatio' but 'corroboratio quædam animæ.' *De Util. Resp.* ch. 1.

[3] Haller, *El. Phys.* iii. 333.

[4] Cf. notes 57, 59.

inspired air acted in the body as the air acts in a stove, and served as a kind of fuel.

This view, of high interest in the history of physiology, as being the starting-point of the modern theory of respiration, was rejected by Aristotle with scanty consideration; and, though a much nearer approximation to the truth than his own later doctrine, was, it must be admitted, justly rejected by him. The air that was given out in expiration was, so far as was then known or believed, precisely similar, save in temperature, to the air that had been taken in, and the suggestion that it served as fuel was therefore quite unmeaning. The one fact on which it rested was the manifest necessity of air for the maintenance of fire. This necessity was, of course, perfectly well known to Aristotle, who points out that, if the air be excluded from the coals in a chafing-pan by shutting down the cover, the fire is extinguished.[1] But for this fact he had, as he thought, an adequate explanation. For, he believed, as did others for centuries after him, that fire could be extinguished, among other agencies, by excess of heat; and that the reason why air prevented such extinction was that it tempered this excess, and kept the heat within necessary limits; a doctrine of which, curiously enough, a remnant still survives in the popular belief that a fire will go out if exposed to the blazing rays of sunshine, the *solis ardoribus*, as Galen said.[2]

Another equally fatal objection in Aristotle's mind to the suggested use of respiration was that, while all animals required their vital heat to be maintained, it was only by a limited number of them that air was inspired. The suggested explanation was, therefore, inadequate to cover

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[1] 470, a, 8. *De Juv. et Sen.* 5, 5.

[2] *De Util. Resp.* ch. 3, where Galen enumerates the various agencies by which fire can be extinguished. So also Aristotle (*Probl.* iii. 23, and xxxiii. 2), 'A small fire can be put out by a large fire or by the sun;' so also Bacon, 'Flame likewise, as Aristotle well observed, is extinguished and overpowered by a greater and more powerful flame; much more the spirit' (Spedding's ed. v. 311).

the facts, whereas his own, to which we shall come presently, as he supposed took them all in.

There remains for mention the view entertained by Plato, which, strangely enough, is not noticed by Aristotle, although, so far as it went, it bore a close resemblance to his own theory. Plato does not appear to have ascribed any use to respiration under ordinary circumstances,[1] but to have supposed that its beneficial effects were limited to certain occasions, when it served to check the ebullition caused by fear or passion. It will be best, however, to state his views in his own words as given in the 'Timæus.' 'But the gods, foreknowing that the palpitation of the heart in the expectation of danger and the swelling and excitement of passion, was caused by fire, formed and implanted as a supporter to the heart the lung, which was in the first place soft and bloodless, and also had within hollows like the pores of a sponge, in order that by receiving the breath and the drink it might give coolness and the power of respiration and alleviate the heat. Wherefore they cut the air channels leading to the lung, and placed the lung about the heart as a soft spring, that, when passion was rife within, the heart beating against a yielding body might be cooled and suffer less, and might thus become more ready to join with passion in the service of reason.'[2]

III

Such were the notions as to respiration that had been promulgated by the foremost minds in Greece when Aristotle turned his attention to the subject. It was at once apparent to him that the mode in which his predecessors had approached the question was not such as could possibly give a satisfactory answer. If you would understand the working of a machine you must first study its structure; nor will even such study be effectual, unless it be guided by the belief that the machine is made to sub-

[1] See, however, note 57.
[2] Jowett's Trans. iii. 492.

serve some purpose or other, to which its structure is adapted. 'The main cause,' says Aristotle, 'of these erroneous statements was the ignorance these writers were in as to the internal organs, and the fact that they had not grasped the truth that nature in all her works has a final cause in view. For had they put the question to themselves, what is the purpose for which respiration exists, and had they sought for an answer by investigating the parts of the animal body, such as the gills and the lungs, they would soon have hit upon the right explanation.'[1]

That the study of function must be preceded by the study of structure, or, in other words, that physiology must be based upon anatomy, seems to us nowadays so trivial and so self-evident a statement, that we can hardly realise that there was a time when its truth was not recognised, and are, in consequence, likely to overlook or underrate the enormous value attaching to its first distinct enunciation. We have, however, only to consider the accounts of the process of respiration given by Aristotle's predecessors, and discussed in the preceding pages, to see that what to us is so self-evident was to them absolutely hidden ; and, reflecting on this, we shall scarcely be disposed to join with those who, finding many strange blunders in Aristotle's physiological conclusions, express astonishment at the renown he has enjoyed for ages as a biologist, and shall admit that, however unsuccessful he may have been at times in the practical application of his method of inquiry, its simple enunciation was in itself an ample justification for the perpetual niche allotted to him in the temple of fame. By insisting on the absolute necessity of anatomical observation, he carried biology at one step from the world of dreams into the world of realities; he set the science on a substantial basis, and may indeed be said to have been its founder, for the vain imaginings of his predecessors can hardly be dignified with the name of science.

[1] 471, b, 23. *De Resp.* iii. 8.

Doubtless, Aristotle thought that his new instrument of research was a much more powerful instrument than is in reality the case. We know now that simple observation will carry us but a little way if unsupported by experiment. That was a truth which had not revealed itself to Aristotle; and though Galen made not inconsiderable use of experimentation, especially in his inquiries into the nervous system, it was not till after nearly seventeen centuries had passed away that its paramount importance in scientific research was distinctly recognised by Roger Bacon, and set forth in such forcible terms as the following:—

'Sed præter has scientias est una perfectior omnibus, cui omnes famulantur, et quæ omnes miro modo certificat; et hæc vocatur scientia experimentalis, quæ negligit argumenta, quoniam non certificant, quantumque sint fortia, nisi simul adsit experientia conclusionis . . . et hæc pars hujus scientiæ extendit se ad cognitionem futurorum et ad operationem mirabilium operum naturæ et artis.'[1]

Of this paramount necessity of experiment and the inadequacy of mere observation for the solution of most problems, Aristotle had no conception. He thought that the functions of the several bodily organs could be deduced from simple observation of their structure; and, with this conviction, he set himself zealously at work to examine the anatomy—internal and external—of all animals that came within his reach. The large number of species of whose organisation notice is to be found in his treatises shows how indefatigable was his industry in this work, though we may assume as highly probable that there were followers and students who aided him in his task. Doubtless his dissections—of which he wrote an illustrated[2] treatise, now unhappily lost—were of a somewhat rough character. He was contented with the coarser anatomy of the parts, the importance of more delicate investigation being neither

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[1] *Opus Tertium*, ch. xiii. p. 44 (Rolls edit.)

[2] *Hist. An.* i. 17, 19, iv. 1, 25, vi. 11, 3; *De Gen.* ii. 7, 6, 497, a, 32, 525, a, 8, 566, a, 15, 746, a, 14.

recognised, nor its prosecution practically possible with such imperfect instruments as were then procurable. The scalpels, whether of iron, copper, or bronze,[1] must have been but clumsy articles, and quite unsuited for following out the course of a nerve or small vessel; the injection of veins and arteries with coloured size had not as yet been devised; there were no magnifying glasses, and no spirits of wine or other fluids to preserve the soft parts or harden them for careful examination, even if such had been thought necessary. Still, to speak of Aristotle's dissections as 'carving-knife' dissections, as some have done, appears to me an unwarranted exaggeration, as any candid person will, I think, allow, if he read the description given of the heart and blood-vessels or of the lung in the 'Historia Animalium.' There are minds to which the mistakes and shortcomings of great men apparently present greater attraction than their achievements. To them Bacon is but a man who believed in the spontaneous generation of mistletoe; Cuvier, an upholder of the fixity of species; Kepler, one who thought that the huge volcanos in the moon were artificial structures built by its inhabitants; Descartes, an assertor of the immediate transmission of light; and Newton himself an advocate of the emission theory. To such persons Aristotle's anatomical statements will doubtlessly supply much desirable pabulum. But those more genial critics, who prefer to dwell upon what a man has done well rather than upon that which he has left undone or done amiss, and who bear in mind, firstly, that the detailed anatomical treatises of Aristotle have been entirely lost, and that consequently our knowledge of his work is based upon such imperfect glimpses as can be obtained from chance extracts in his other writings; and, secondly, that this branch of science and this method of investigation was entirely new, and that the results obtained are therefore to

[1] A large proportion of the surgical instruments found at Pompeii were apparently made of copper, the rest of iron. See Smith's Dict. *sub* 'Chirurgia.'

be judged with much indulgence—such critics, I say, will admit that never has a science been started on its career by its originator with so large an equipment of facts and ideas as that with which Comparative Anatomy left the hands of Aristotle. We may apply to his work in this department the words in which he speaks of his labours in another field of knowledge. 'I found,' he says, 'no basis prepared, no models to copy. . . . Mine is the first step, and therefore a small one, though worked out with much thought and hard labour. It must be looked on as a first step, and judged with indulgence. You, my readers or hearers of my lectures, if you think I have done as much as can fairly be required for an initiatory start, compared with other more advanced departments of theory, will acknowledge what I have achieved, and pardon what I have left for others to accomplish.' [1]

We can well imagine with what contemptuous surprise the followers of the old *a priori* school must have regarded the new departure. To minds engrossed in speculation as to celestial phenomena, or as to the ultimate nature of things and the cosmos, the study of the structure and offices of the organs of the body must have seemed an ignoble pursuit, beneath the dignity of a philosopher; and especially so, when it was seen that such study could only be prosecuted by the repulsive handling of the viscera of the lower animals, the internal parts of man himself, owing to the religious feelings of the Greeks, being quite inacccessible to the anatomist. Their attitude and their arguments may be inferred from the following stately passage in the 'De Partibus,' in which Aristotle answers this class of objectors :—'Some members of the universe are ungenerated, imperishable and eternal, while others are subject to generation and decay. The former are excellent beyond compare and divine, but less accessible to knowledge. The evidence that might throw light on them, and on the problems which we long

[1] *Soph. Elench.* xxxiv. as rendered by Grote.

to solve respecting them, is furnished but scantily by sensation ; whereas respecting perishable plants and animals we have abundant information, living as we do in their midst, and ample data may be collected concerning all their various kinds, if only we are willing to take sufficient pains. Both departments, however, have their special charm. The scanty conceptions to which we can attain of celestial things give us, from their excellence, more pleasure than all our knowledge of the world in which we live ; just as a half glimpse of persons that we love is more delightful than a leisurely view of other things, whatever their number and dimensions. On the other hand in certitude and completeness our knowledge of terrestrial things has the advantage. Moreover their greater nearness and affinity to us balances somewhat the loftier interest of the heavenly things that are the objects of the higher philosophy. Having already treated of the celestial world, as far as our conjectures could reach, we proceed to treat of animals, without omitting, to the best of our ability, any member of the kingdom, however ignoble. For if some have no graces to charm the sense, yet even these, by disclosing to intellectual perception the artistic spirit that designed them, give immense pleasure to all who can trace links of causation, and are inclined to philosophy. Indeed, it would be strange if mimic representations of them were attractive, because they disclose the mimetic skill of the painter or sculptor, and the original realities themselves were not more interesting, to all at any rate who have eyes to discern the reason that presided over their formation. We therefore must not recoil with childish aversion from the examination of the humbler animals. Every realm of nature is marvellous ; and as Heraclitus, when the strangers who came to visit him found him warming himself at the furnace in the kitchen, is reported to have bidden them not to be afraid to enter, as even in that kitchen divinities were present, so we should venture on the study of every kind of animal without

distaste ; for each and all will reveal to us something natural and something beautiful. Absence of haphazard and conduciveness of everything to an end are to be found in Nature's works in the highest degree, and the resultant end of her generations and combinations is a form of the beautiful.

'If any person thinks the examination of the rest of the animal kingdom an unworthy task, he must hold in like disesteem the study of man. For no one can look at the primordia of the human frame—blood, flesh, bones, vessels and the like—without much repugnance. Moreover, in every inquiry, the examination of material elements and instruments is not to be regarded as final, but as ancillary to the conception of the total form. Thus the true object of architecture is not bricks, mortar or timber, but the house ; and so the principal object of natural philosophy is not the material elements, but their composition, and the totality of the form to which they are subservient, and independently of which they have no existence.' ('De Part.' i. 5.)

IV

We have now to consider how it fared with Aristotle in his attempt to throw light on the mechanism and use of respiration by means of anatomical researches.

He found that all Vertebrates,[1] or all Sanguineous animals, as he preferred to call them—inasmuch as the presence of red blood was from his point of view a more important character than the presence of a back-bone—had lungs, with the exception of fishes, who were furnished with gills. No animal had at the same time gills and lung, for the perennibranchiate amphibia and the mud-fishes were of course unknown to him ; and from this mutual exclusion, and the invariable presence in every red-blooded animal of one or the other organ, he inferred that the functions of the two were identical, and stood in some direct relation to the blood. In no animal without

[1] That sanguineous animals corresponded to vertebrata was recognised by Aristotle. Cf. 516, b, 22. *Hist. An.* iii. 7, 12.

true blood, that is in no invertebrate animal, was there, as he supposed, either lung or gills, and he inferred that owing to their want of blood they required no such special organ, its duty being in their case adequately fulfilled by the general surface of the body.

At first one is astonished that Aristotle should not have detected the existence of branchiæ in any of the numerous invertebrates that he dissected. He knew that in many of them, and notably in cephalopods and crustaceans,[1] water is alternately taken in and discharged as in fishes, and one would have supposed that this similarity by itself would have suggested and led to the discovery. But he imagined that this passage of water to and from the body of the invertebrates was not analogous to the similar process in fishes, but corresponded to the necessary admission of water in company with its food into the mouth of a porpoise or other cetacean and its subsequent supposed discharge through the blow-hole.[2]

He cannot of course have failed to see the branchiæ over and over again in his dissections, and it is generally supposed that the hair-like appendages (*τὰ τριχώδη*) which he mentions as existing in cephalopods,[3] and still more distinctly as forming a circle or fringe[4] in mollusks, and especially in scallops, were in reality the branchiæ of these animals; but that he should not have so interpreted these appendages is perfectly intelligible. One of the most essential characters of a gill was that its surface should be richly supplied with blood, or fluid analogous to blood. In the fishes' gills the presence of such blood was manifested by the red colour of the part; but in invertebrates, where the blood was colourless there was no such indication, and the instruments at Aristotle's command were quite inadequate for the detection of the excessively minute vessels. The branchiæ of these animals had therefore nothing to

[1] Cf. note 121. [2] Cf. note 118.

[3] 524, b, 21. *Hist. An.* iv. 1, 20.

[4] 529, a, 32. *Hist. An.* iv. 4, 22.

distinguish them from any other much subdivided processes, and in fact the appendages which struck him as bearing the most resemblance to gills, and of which alone he speaks as being 'branchiform' in aspect, were not the gills themselves but the various palps and shaggy processes round the mouths of the decapodous crustacea.[1]

The only invertebrate or bloodless animals in which Aristotle appears to have suspected the presence of any special organs of respiration were the insects. He had observed in some of these an alternate expansion and contraction of the abdomen,[2] and the resemblance of this motion to that of the mammalian thorax led him to conjecture that it might serve an analogous purpose. The humming noise, again, made by some insects differed, he noticed, from the stridulation produced by friction of certain parts of the integument,[3] and resembled a sound made by a current of air, when 'a child blows through a reed in which it has bored a hole and covered the orifice with a thin membrane.'[4] Unable, therefore, to see the orifices and tubes of the tracheal system, which were too minute for his powers of dissection, he hunted for some structure in the abdominal region of insects which should resemble the child's pipe; and found it in the so-called drums of the cicadæ, which are largish orifices, covered by a tense and delicate membrane, at the base of the abdomen of those insects, and he supposed that these drums were instruments both of respiration and of sound. It is true that similar drums[5] were not to be found in other humming species, such as bees and flies, and Aristotle had to assume that they, or some analogous parts, were there though he could not find them, possibly imagining that they lay hidden in

[1] See note 121.

[2] 475, a, 10. *De Resp.* 9, 3.

[3] 535, b, 12. *Hist. An.* iv. 9, 4. Cf. note 87.

[4] 475, a, 15. *De Resp.* 9, 5.

[5] For a full and comparatively recent description of the drums, see Carlet, *Ann. des Sc. Nat.* 1877, série 6, t. v. They are only found in the male cicadæ, being rudimentary in the voiceless females; but there are somewhat similar organs in certain crickets.

some part of the thinner integument between the successive abdominal segments.

Imperfect and vague as these observations and conclusions were, they are not only of much interest, as being the first attack on a problem which it took twenty more centuries to solve, but contain a considerable proportion of truth, and bear witness to the sagacity of the observer. For it is now a thoroughly established fact that the abdominal motion in insects is really subservient to respiration, it being this that determines the entrance and discharge of air into and from the tracheal system,[1] and it is also a fact, which if not thoroughly established is accepted as most probable by almost all [2] naturalists, that the office of the drums of the cicadæ is, as Aristotle suggested, the production of sound.

Putting aside the failure of Aristotle to detect the actual organs of respiration in insects or other invertebrates, his answer to the question whether all animals respire may be stated in terms which coincide pretty nearly[3] with the teaching of modern science. Respiration, he said, is confined to animals that inhale and exhale air by means of lungs, but the same result as is obtained by lungs in the most highly organised groups of animals is obtained in the animals that come next after them in the scale by means of gills, and in animals of still lower grade by the general surface of the body; insects, however, or certain insects, having some special apparatus for the purpose.

Let us now consider what Aristotle made out as regards the organs of respiration in the vertebrate or sanguineous

[1] It is curious that Malpighi, who in 1688 discovered the tracheal system of insects (*Opera omnia*, Lond. 1687, vol. ii., *Opera postuma*, p. 56), should have hesitated to accept the respiratory office of this abdominal motion, though obviously inclined to do so. Cf. *op. cit.* *De Bombyc.* p. 15.

[2] Landois (*Zeitschr. f. wissensch. Zool.* xvii. 135, and xxii. 350) does not accept the ordinarily received views as to the function of the drums. Still he speaks of Aristotle's notice of them as 'bewunderungswürdig sinnreich.'

[3] Exception may be made on the ground that some spiders and gasteropods are pulmonate.

animals. The organs which we call lungs were considered by Aristotle to be the right and left halves of an azygous organ, and were therefore spoken of by him in the singular; his reason for so doing being that in many snakes[1] the organ is actually single, and that in animals where it is double the two parts have a common outlet, namely, the windpipe. Still he admits that the two parts are so widely separated, especially in ovipara, as to look like two organs, and that in reality all the organs of the body may be held to be double.[2]

There is no organ in the body, he says, at any rate in the pulmonate vivipara, that is in mammalia, so richly supplied with blood as the lung, and those who, like Plato, have described it as bloodless must have founded their belief on the examination of specimens from which the blood had been allowed to escape.[3] Lungs are closed sacs, having no communication with any other internal organ than the heart, with the right and left cavities of which they communicate by blood-vessels, nor with the external air, excepting through the cartilaginous windpipe and larynx. This opens into the œsophagus at such an awkwardly situated point that, were it not for a special provision, food would be likely to get into it during deglutition. 'To obviate this, nature has contrived the epiglottis. This part is not found in all animals,[4] but only in such of them as have a lung; nor in all of these, but only in such as at the same time have their skin covered with hairs (i.e. *mammalia*), and not either with scaly plates or with feathers (i.e. *reptiles and birds*). In such scaly or feathered animals there is no epiglottis, but its office is supplied by the larynx, which closes and opens just as in the other case the epiglottis falls down and rises up, rising up during the ingress or egress of breath, and falling down during

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[1] 508, a, 32. *Hist. An.* ii. 17, 22.

[2] 669, b, 18. *De Part.* iii. 7, 1.

[3] 496, b, 5-511, b, 14. *Hist. An.* i. 17, 7, iii. 2, 3.

[4] For ζωοτοκοῦντα in the passage here translated I read ζῷα, a necessary emendation.

the ingestion of food, so as to prevent any particle from slipping into the windpipe. Should there be the slightest want of accuracy in this movement, or should an inspiration be made during the ingestion of food, choking and coughing ensue. So admirably contrived, however, is the movement both of the epiglottis and the tongue, that, while the food is being ground to a pulp in the mouth, the tongue very rarely gets caught between the teeth; and, while the food is passing over the epiglottis, seldom does a particle of it slip into the windpipe.'[1] This shows, he says, how ridiculous is the notion entertained by some persons that the lung is a channel through which an animal imbibes fluid. Among those who held this extraordinary belief is to be numbered Plato, though he is not actually named by Aristotle; and perhaps the stride made by Aristotle in biological knowledge can scarcely be better exemplified than by contrasting his views of the lungs with those of his immediate great predecessor, who held them to be bloodless organs, which serve, with other purposes, as a receptacle for drink.[2]

As regards the internal structure of the lungs, the following is Aristotle's account, as gathered from several scattered passages.[3] The windpipe divides at its lower end into two great branches (the *bronchi*) which go to the right and left halves of the lung—or, as we should say, to the right and left lungs—respectively. When the branch has entered the lung, it divides into smaller air-tubes (*σύριγγες*) which contain cartilage in their walls, and ramify by bifurcating at an acute angle. From these cartilaginous bifurcations are given off passages (*τρήματα*) that divide

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[1] 664, b, 21. *De Part.* iii. 3. Aristotle is perfectly correct in saying that mammalia alone have an epiglottis, and that its office is fulfilled in other vertebrates by the constriction during deglutition of the laryngeal orifice. This is visible, and may very possibly have been seen by Aristotle, on looking into the wide gaping mouths of very young birds when fed.

[2] See passage from the *Timæus* quoted at p. 28. That drink passed into the lungs was perhaps the current belief before Aristotle. For we find in Alcæus, *τέγγε πνεύμονας οἴνῳ* (*Fragm.* xviii.).

[3] 495, a, 496, a and b, 513, b. *Hist. An.* i. 16, 8–15, i. 17, 5, iii. 3, 15.

and subdivide, becoming smaller and smaller with each successive subdivision, until they permeate the whole organ. The blood-vessels that come to the lung from the right and left cavities of the heart (*pulmonary artery* and *pulmonary veins*) divide and subdivide in exactly the same way as do the air-passages, and accompany them in all their ramifications, becoming, like them, smaller and smaller with each successive division, and the branches of the vessel from the left cavity (*pulm. veins*) being always smaller than the branches of that which comes from the right (*pulmonary artery*). The subdivision at last reaches a point, when it can no longer be followed by the eye, but so completely is the lung occupied by these channels for air and for blood that no bit of it can be found, however small, in which there is not to be seen both an air-passage and a minute blood-vessel. Thus air-passages and blood-vessels are throughout in immediate juxtaposition. They remain, however, perfectly distinct, and there is no direct communication between them. Nevertheless the close contact in which they lie allows inspired air to pass from the former to the latter.

This description of the lung-structure, so far as it goes, is perfectly accurate, and considering the period when it was made, and the inadequate appliances then existing for anatomical investigation, cannot but be regarded as a notable achievement.

Such being the anatomical structure of the lungs, the next question was to what purpose was it adapted. It was plainly an arrangement to bring the air and the blood into communication; for when the lung is expanded air flows in, and when it subsides the air is again expelled. But how is this alternate expansion and subsidence brought about, and what is the purpose for which air and blood are brought into contact? The heart, says Aristotle, is placed in the centre of the body, with lung on either side of it. Now the heart is the seat of the soul, or vital principle, which is embodied in a fiery substance as its

necessary substratum. This fire is being perpetually fed with fuel derived from the food, and depends for its maintenance on such supply. If fuel be withheld, as in starvation, the fire is exhausted, and practically the same result is produced, if the fire be so intense as to consume the fuel faster than it is supplied. But the fire in the heart is always threatening to do this, and consequently requires to be kept within bounds. The moderating agents that effect this are the lungs; for, when the heat in the heart becomes excessive, it causes the closely adjoining lung to expand, and the expansion of the lung again involves the expansion of the thorax in which it lies. But when the lung expands, cold air flows into it from without. This reduces the heat, and thorax and lung again subside, and the inhaled air which has been heated by contact with the blood is expelled. Again the heat rises, and again the process is repeated, and so on continuously in unbroken alternation of inspiration and expiration. This action of the lungs resembles that of a smith's bellows. 'There is, however, this difference. The air in the bellows is not admitted by the same channel as that by which it is discharged; whereas one and the same channel serves alike for inspiration and expiration.'[1]

In this ingenious hypothesis, the vital heat is made to be its own regulator; for it is by it that the mechanism is set in motion by which all excess is prevented and the heat kept within due limits; and, as such restriction of heat is a necessary condition of its maintenance, the ultimate effect of respiration, in spite of its transient refrigerating influence, is, to use the words of Galen, as quoted by Haller, *conservatio caloris naturalis per refrigerium.*

As the end of respiration is to bring air and blood into practical contact with each other, it is plain that, *cæteris paribus*, that lung will be most efficient which is the

[1] 474, a, 17. *De Resp.* 7, 17.

largest, the most richly supplied with blood, and has the most minutely divided air-passages, so as to present the amplest surface of contact. These 'conditions of perfection' were fully recognised by Aristotle, who correctly states that they are best fulfilled by the lungs of mammals, the lungs in the other pulmonate vertebrates being comparatively small and bloodless, and of a more pronounced spongoid character (σομφός), or of membranous consistency (ὑμενώδης), with large insterstices in their substance like the bubbles in foam.[1] These differences in the perfection of the lungs of animals, as also corresponding differences in the development of the gills of fishes, Aristotle supposed to be correlated with differences in their vital heat, and therefore to supply a measure of their position in the scale of being. For in proportion to the vital heat would be the necessity of provision for its regulation.

Having discussed at some length Aristotle's account of the structure and use of the lungs, it will be unnecessary to give much time to his views concerning the gills. That Aristotle examined these organs with some care is shown by the numerous observations he makes as to the differences they present in different fishes in regard to their position and number, their singleness or doubleness, and the presence or absence of an operculum.[2] But as to their form and structure he says nothing. All he tells us is that a branch goes to each gill from the blood-vessel that issues from the anterior end of the heart, that is from what we know as the bulbus arteriosus and branchial artery.[3] As to the process itself, the account he gives is that the refrigeration, which in pulmonate animals is effected by air, is in fishes effected by water, which is taken in at the mouth and discharged through the branchiæ at the gill openings. The alternate expansion and contraction of the branchial apparatus which determine this current of water is, he says, brought about by the same

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[1] Cf. note 44.

[2] 505, b. *Hist. An.* ii. 13.

[3] Cf. note 136.

cause as the corresponding motions of the lungs,[1] namely, the alternate heating and cooling of the blood in the heart and blood-vessels; and just as lungs differ in perfection according to the extent of surface they present to the refrigerating medium, so also do the gills; for these are small, few, or single in such fishes as are of a frigid character, and large, numerous, or double in those that are of a hotter nature.[2] In some fishes, moreover, the passage of water through the gills, and consequently the refrigeration, is lessened by the small size of the gill apertures; and Aristotle attempts to explain on this basis the fact that eels and similar fishes can live out of water for a considerable period. The reduced size of their gill-slits shows, he says, that they are animals that have comparatively small need of refrigeration.

That the long maintenance of life by eels when kept out of water stands in connection with the small size of their gill-openings has, from Aristotle's days to our own, been the accepted view of naturalists, though their explanation of this connection, it need hardly be said, differs widely from his, and is based on the supposed preservation of the branchiæ from desiccation. But experimental evidence has of late years been adduced by Paul Bert,[3] which seems to show that this generally adopted explanation is in fact inadequate, and that the main reason for the prolongation of life of these fishes in the air is that the vital changes which are dependent upon the absorption of oxygen go on in eels with much less intensity than in the generality of fishes, and that consequently they have, as Aristotle had said, less imperative demand for respiration. Nor is Aristotle's statement, that the adequacy of gills to perform their special office varies with the extent of their surface—an opinion, the truth of which might be accepted on merely *a priori* grounds—without its corroborative evidence. For it has been shown

[1] 478, b. *De Resp.* 16, 5, and 480, b, 12. *De Resp.* 21, 5.

[2] 696, b, 16. *De Part.* iv. 13, 19.

[3] *Leçons s. la Resp.* pp. 254–266.

by the experiments of Flourens that the main reason why an ordinary fish dies so rapidly in the air is not that its gills are unable to act in that medium, but that, when no longer floating freely in water, they collapse into a heap, and that by this collapse the surface they present to the air is so enormously reduced as to more than counterbalance the greater richness of oxygen in that medium than in their natural element.[1]

V

Such, then, were the conclusions as to the organs, the process, and the utility of respiration to which Aristotle was led by his anatomical investigations. Looked at in the strong light of modern science, the errors and the inadequacies of the theory are glaringly conspicuous. But if we perform the difficult task of excluding from our minds all ideas and facts since acquired, we shall, I think, find ourselves constrained to admit that in Aristotle's days no better hypothesis could have been devised with which to colligate the facts, or supposed facts, then available.

Among these, however, there was at any rate one, for which it must have been difficult to find satisfactory explanation in the hypothesis; and as it occupied a prominent place in the speculations and researches of all later natural philosophers, until after some twenty centuries it was made to yield up the secret of respiration, it will be well to devote some little space to its consideration. It was well known to Aristotle that an animal confined in a limited amount of air or water soon perishes,[2] and with sagacious insight he placed this fact side by side with the extinction of fire under similar conditions, as when the lid of a chafing-pan is kept down, and the burning embers within shut off from all access of air.[3] How were these notable phenomena to be explained? It was clear that

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[1] *Ann. d. Sc. Nat.* 1830, xx. 5.

[2] Cf. note 137.

[3] 470, a, 8. *De Juv.* 5, 5.

in one case combustion, in the other respiration, had wrought some change in the medium that rendered it unfit for the maintenance of these processes. This change we know now to consist in the loss of oxygen and the increase of carbonic acid gas; but all such chemical changes were, of course, utterly unknown in the days of Aristotle, and for many long centuries afterwards, and not the least suspicion was entertained of the existence of any invisible aeriform bodies other than air itself. The only assignable alteration in the medium was that it had presumably become somewhat hotter than before; and though mere immersion of the hand — thermometrical instruments being then unknown—would have shown that death ensued long before the medium was notably, or, in the case of fishes in water, before it was perceptibly heated, and indeed when it had been kept purposely at a very low temperature, it was naturally and indeed almost necessarily to this, as the only imaginable alteration, that Aristotle ascribed the fatal result. The animal died because the medium was no longer cold enough to produce the requisite refrigeration; the flame was extinguished because its fuel was consumed too rapidly by the untempered heat.[1] The notion apparently was that the flame of a lamp is fed by the oil mounting up in the wick, but that when the heat of the flame is very intense it consumes the oil faster than it can be supplied, and the flame consequently goes out for want of sustenance. This was, indeed, the mode in which Aristotle supposed death to be produced when the cardiac fire was not tempered by respiration. The fire was fed by vapour of food rising up from the stomach through the blood-vessels, as the lamp is fed by oil rising up through the wick, and when the cardiac fire became too intense from lack of refrigeration, it burned up its fuel faster than the stomach could supply it, and, like the flame of the lamp, perished from inanition.

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[1] Cf. note 34.

How Aristotle managed to get over the obvious fact that, when an animal is shut up in a box or other close receptacle, death ensues before the apparent heat of the medium is materially increased, we can only surmise. Possibly the very simple experiment that would have shown this was not made by him. The difficulty, however, would not have appeared so insuperable to him as it appears to us ; for not only were the notions of the nature of heat at that time extremely vague, but it was held by Aristotle that touch was a very inadequate test of the presence or absence of heat, and that the amount of this could be gauged by much more certain indications than mere tactile impressions. For instance, a snake, a fish, and a calamary all appear indistinguishably cold to the hand, but in Aristotle's belief the difference in their respective temperatures was enormous, the snake being much hotter than the fish, and the fish than the calamary. This he inferred with unhesitating confidence from their structure ; for heat was the necessary agent in the development of the body, and the more complex the organism the greater must have been the heat that produced it. Probably it was by some such considerations as this, as showing that heat might exist in bodies in, so to speak, a state of latency, and without manifesting itself to touch, that Aristotle got over the difficulty. It may be well, however, to inquire very briefly how those later physiologists who accepted Aristotle's theory that the necessity of respiration lay in the need of refrigeration explained the rapid death of an animal, and the analogous extinction of fire, in a limited amount of air. Galen, for instance, held the doctrine of refrigeration, and also agreed with Aristotle in regarding respiration and combustion as nearly allied processes. If, he says, we could only tell what are the causes that bring about the extinction of fire, we could also tell what is the reason why an animal dies when its respiration is prevented. Now one of the main causes of the extinction of fire is the accumulation of smoke and fuliginous matter, and from this it is

to be inferred as probable that smoke and fuliginous matter are produced by the fire within the heart, and that, when respiration is stopped, these accumulate and choke the vital flame.[1]

This explanation was open in the first place to the manifest objection that no visible smoke or fuligo, such as is given off by an ordinary fire, is detectible in the expired air, and, as already stated, there was in those days no suspicion of the existence of invisible gaseous bodies other than air; and, secondly, to the further objection that the extinction of fire by accumulated smoke is simply due to the fact that the smoke prevents the access of air, and clearly affords no explanation whatsoever of why air is necessary. Many centuries later ingenious attempts were made to show that accumulated smoke would extinguish a flame not simply by depriving it of air, but by more direct action, and that the need of air consisted merely in its furnishing a current by which smoke could be carried away and accumulation round the flame be prevented. Thus it was suggested by Van Helmont that the exhalation of smoke or fuligo is a necessary condition of all combustion, and that, if such exhalation be prevented, combustion is thereby made impossible. Now smoke occupies space, and must, when exhaled, have some place in which to lodge; this it finds in the 'vacuities or emptinesses of the air,' that is, in the interspaces between the aerial particles. But

[1] 'Ego vero cum fornacem viderem, ob id quod perspirationem non haberet, extingui, et postea ipsum aperiri, atque tum multam fuliginem exspirare, tum multum purum aerem externum inspirare, atque utroque facto flammam splendorem recipere, non parvam esse rationatus sum exspirationis utilitatem ad hoc, ut id, quod veluti fuligo sanguinis est, evacuetur. Favilla enim et fumus et fuligo, et omnis hujusmodi ustæ materiæ superfluitas, nihilo minus quam aqua, ignem extinguere consuevit. Quare ex omnibus potissimum recipiendi sunt, qui dicunt insiti caloris gratiâ animalia respirare. Nam et moderate ventilari utile est et mediocriter refrigerari. Ambo enim hæc internam caliditatem videntur corroborare; necessariumque est motum habere ad fuliginosum, ut ita loquar, extra evacuandum quod a sanguinis naturâ redundat. Hæc quidem scientificam persuasionem non habent neque necessariam demonstrationem, qualem in aliis semper adducere in usu habemus: non tamen fide omnino carent.'—*De Utilit. Respir.* chapter 3.

when a flame is burning in a confined space, these 'vacuities' are soon filled, and the sooner of course the smaller the space, and when this occurs no more smoke can be given off, and consequently 'the fire, being deprived of air, perishes; not indeed in respect of denied nourishment or of a participated life, but for want of room which cannot contain the smoak.'[1] This explanation, which was adopted by other and later writers, received its death-blow from Boyle and Mayow, who pointed out[2] that, were it true, a candle should burn, and an animal survive, longer under a bellglass from which the air had been partially or wholly removed by the air-pump than under one in which it had been left, for the exhausted glass would clearly afford more space for the smoke; but that, as a matter of fact, the very contrary was the case, the removal of the air causing more rapid extinction both of flame and life. This observation of Boyle was equally fatal to another attempted explanation, advanced by Lord Bacon. When the wick of a lighted candle or a bit of burning coal is closely compressed between the flat ends of a pair of tongs, the fire is at once extinguished. This extinction Bacon attributed to the pressure, and he argued that when a candle is burning in a confined space, the air is expanded by the heat of the flame, and puts this out by the pressure it exercises on the wick.[3]

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[1] Van Helmont's *Works*, Eng. Transl. 1662, p. 84. Although Van Helmont propounded this theory, in a later passage (p. 159) he says that a flame is extinguished, when put into a vessel in which a previous flame has burnt to extinction, 'by a wild gas, the onely odour whereof extinguishes a new flame,' and he speaks vaguely of the same gas extinguishing life. His 'wild gas' was of course the carbonic acid of later days.

[2] 'Upon the exsuction of the air, the animal dies a great deal sooner than if it were left in the vessel; though by that exsuction the ambient space is left much more free to receive the steams that are either breathed out of the lungs of the animal or discharged by insensible transpiration through the pores.' Boyle's *Works*, i. 104. Mayow (*Quinque Tract.*, Oxford, 1674, p. 11) uses the same arguments as to the burning of a candle under a glass.

[3] 'Flame, if it be too much compressed, is extinguished, as may be seen by putting a glass over a candle. For the air, expanded by the heat, compresses the flame, and thereby lessens and extinguishes it. . . . Ignited bodies are also extinguished by compression; for if you press a burning coal hard

VI

And this brings us to the final topic to be handled in this introductory essay, namely, the ultimate fate of Aristotle's doctrine of respiration. It had apparently been the belief of Aristotle's immediate predecessors that the expansion and subsidence of the thorax, which visibly accompany the act of respiration, are brought about by the alternate admission and discharge of air. Aristotle inverted this statement, and taught that the expansion and subsidence are not the consequence but the cause of the air's motion to and from the thoracic cavity; and this basal fact in the mechanism of respiration, together with the apt simile in which Aristotle compared the action of the thorax to that of the bellows in a smithy, remains stereotyped in every handbook of physiology to the present day.[1]

Aristotle, however, further taught that the force which put the thoracic bellows in motion was heat developed in the heart. This erroneous part of his teaching was not destined to long survival. Who it was that first overturned it cannot be stated with certainty. But by the time of Galen it was a thoroughly established fact that the movements of the thorax are due to muscular action, and that

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with the tongs or with your foot, the flame is immediately put out.'—Bacon's *Works*, Spedding's ed. v. 311.

[1] A distinction must be made between the expansion of the thorax and the expansion of the lungs. Aristotle erroneously thought that both were comparable to the expansion of bellows, which is the cause of the entrance of air, whereas the thorax alone resembles bellows, and the lung is rather to be compared to a bladder which the entrance of air dilates. This was pointed out by Boyle: 'Some maintaining that the chest with the contained lungs may be resembled to a pair of bellows which comes therefore to be filled because it was dilated; and others pleading to have the comparison made to a bladder, which is therefore dilated because it is filled. For as to the thorax, it seems evident from what has been lately said that it, like a pair of bellows, happens to be partly filled with air, but because it was dilated; but as to the lungs themselves, who want fibres to distend them, they may fitly enough be compared to a bladder, since they are dilated by being filled' (*Works*, i. 101).

great physiologist was even able to give details as to the precise muscles engaged in the process, and to state that the one on which the main part of the duty devolves is the diaphragm.[1]

Much longer lived was Aristotle's doctrine of the use of respiration. This remained master of the field for more than eighteen centuries after his death. Not, however, without antagonists; for there were always some, and perhaps many, who held that the effect of respiration was not refrigeration but the production of heat.[2] These two rival hypotheses, however, as has been already noted, were not so diametrically opposed as would at first appear to be the case. For to Aristotle as much as to his opponents the *ultimate* effect of respiration was the maintenance of vital heat. The difference between them was not as to the ultimate effect, but as to the mode in which this effect was brought about. Aristotle said that excess of heat was incompatible with the maintenance of fire, and that the inspired air acted by carrying this excess away, to which Galen further added that it also carried away the fuliginous matter, and other '*ustæ materiæ superfluitas*,' which would extinguish the fire, if allowed to accumulate; while Aristotle's and Galen's opponents held that the action of air in the production of heat was more direct; for that in some unexplained way it supplied the fire with fuel. We know now that this surmise was correct, and that the fuel

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[1] *De Causis Resp.* and *De Util. Part.* iv. 14.

[2] There was also the view of Erasistratus, that the purpose of respiration was the introduction of air into the arteries for the formation of vital spirit; this physiologist having made the blunder—often erroneously attributed to Aristotle—of supposing that the arteries contain air and not blood. But that the inspired air served for the formation of spirit was an opinion that could be held in conjunction with that of Aristotle that it served for refrigeration; and it was held in such conjunction. For Boyle, in his enumeration of the various opinions held as to the use of respiration in his time, says that some maintain 'that air gets into the left ventricle, not only to temper its heat, but to provide for the generation of spirits.' There was also the doctrine, already discussed (p. 24), that the utility of respiration consisted in its facilitating the action of the heart.

supplied by the air is oxygen, while the '*ustæ materiæ superfluitas*' of Galen is carbonic acid, and that the supply of oxygen for combustion, and the carrying away of the carbonic acid, that is its result, are in fact the great uses to which respiration is subservient; but in ancient days, and for the first sixteen centuries of our own era, the surmise that air served as fuel was quite unintelligible, and Aristotle's less true, but more intelligible, hypothesis was naturally, and properly, the one generally accepted.

It was not till the latter half of the seventeenth century that Aristotle's doctrine as to the use of respiration received its death-blow. Of the experiments that brought this to pass, the most directly fatal was one made by Robert Boyle. Starting from the fact, already noted by Aristotle, that an animal confined in a limited amount of unrenewed air soon perishes, he showed that this result is neither prevented nor delayed by surrounding the vessel in which the animal is confined with ice or a freezing mixture, and so keeping the air within at a much lower temperature than that of the actual atmosphere; and, when to this experiment was added by other physiologists the observation that an animal can maintain life in air which is much hotter than its own blood,[1] the theory of refrigeration clearly ceased to be any longer tenable. For the animal in the one case continued to live in air that could not possibly cool its blood, and in the other died when the conditions for the supposed refrigeration were more than usually favourable.

It is, however, not to be expected that a structure, which has stood for well-nigh twenty centuries, should yield to the first serious attack made upon it, and vanish like "the baseless fabric of a vision." Some "rack" will certainly be left behind; and it need therefore be no matter of surprise to find the doctrine of refrigeration, in spite of the deadly blow given to it by such experiments

[1] 'Vivitur in aere qui sanguinis calorem superat.'—Haller's *El. Phys.* iii. 346.

as that of Boyle, still maintaining a lingering existence for full another century. It was upheld before the French Academy of Sciences by Helvetius[1] in 1718, and found a warm advocate in Hamberger[2] in 1751; and probably diligent search through the musty works of the latter part of the eighteenth century would reveal the names of still later, if less distinguished, supporters. The doctrine of Aristotle, however, as held by these physiologists, had undergone one most important modification. Aristotle, as we have seen, had taught that the use of refrigeration was to prevent the vital heat from being exhausted by its own excess; and this original doctrine had not become extinct in the earlier half of the seventeenth century, for we find it in the treatise of Fabricius of Acquapendente on respiration,[3] and still later in Sir Thomas Browne's 'Pseudodoxia Epidemica.'[4] But Helvetius, Hamberger, and their followers, and indeed some of their predecessors, such as Descartes[5] and Swammerdam,[6] had altogether abandoned this notion, and held that the main use of refrigeration was to bring about the condensation of the blood. Were it not for such condensation, said Helvetius[7]

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[1] *Mém. de l'Acad. Roy. d. Sciences* for 1718.

[2] Hamberger, *De Resp. Mechan. atque Usu Genuino.*

[3] 'Caloris tutelam potissimum in ejus refrigeratione consistere, ostensum jam est; hanc autem aerem frigidâ suâ qualitate præstare, et hoc quoque est notissimum,' and again, 'aeris attractionem sequitur caloris refrigeratio et denique ejus tutela et conservatio.'—Fabricius, *De Respir. et ejus Instrum.* Patavii, 1625. Lib. i. c. 4.

[4] 'The proper use of ayre attracted by the lungs, and without which there is no durable continuation in life, is not the nutrition of parts, but the contemporation of that fervor in the heart, and the ventilation of that fire alwaies maintained in the forge of life.'—*Vulgar Errors*, iii. 21.

[5] Descartes (Cousin's ed.), iv. 339 and 446.

[6] *Tractatus de Respir. Usuque Pulm.* (Lugduni Batav. 1738), cap. 1, § ix. p. 2.

[7] Helvetius further supposed that the condensation of the blood made it more fluid. 'Le principal usage de la respiration . . . est de diminuer la raréfaction du sang, de le condenser, de réunir toutes ses parties et de lui donner plus de fluidité. Puisqu'il est certain que les liqueurs en ont souvent davantage, étant condensés, qu'elles n'en avaient, lorsqu'elles étaient raréfiées.

and Hamberger,[1] the blood which has been heated and rarefied in its passage through the veins, and which therefore arrives at the right side of the heart with increased bulk, would be unable to pass through the lungs to the left cavities, inasmuch as both these and the blood-vessels which lead to and from them are of smaller dimensions than the corresponding cavities and vessels of the right heart. That the systemic arteries are of smaller capacity than the corresponding veins is an unquestionable fact, but, as Helvetius himself admits, this smaller capacity can be compensated by the blood flowing more rapidly through them in consequence of their more muscular walls and the greater *vis a tergo* supplied by the left ventricle; but whether there is a similar difference between the pulmonary arteries and veins, or between the right and left ventricles, is, to say the least, excessively doubtful.[2] If such a difference exists, it must be very slight, and can be compensated by the right ventricle contracting under ordinary circumstances before it is fully distended, and when the blood within it is only equal in amount to that in the corresponding cavity on the left. How the physiologists who put forth this new and ingenious argument in favour of the refrigerating use of respiration got over the apparently insuperable objection to that theory presented by Boyle's experiment it is difficult to imagine. We can hardly suppose that they were ignorant of that and other similar experiments, and yet, so far as I have been able to discover, there is no reference whatsoever to

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Ce qui se découvre visiblement dans l'eau de savon et de chocolat, qui deviennent moins fluides, lorsqu'ils sont moussés que quand ils ne le sont pas.' —*Op. cit.* p. 244.

[1] 'Immediatus igitur respirationis usus est refrigeratio massæ sanguineæ, ex quo oritur secundus, condensatio, et hunc excipit tertius, cujus causæ priores sunt, circulatio nempe massæ sanguiniæ, minima vero, uti plurimorum est opinio, miscela aeris cum massâ sanguineâ.'—*Op. cit.* i. § lxvi.

[2] Some anatomists, as Winslow, Santorini, and Haller, think that the pulmonary veins are slightly smaller than the corresponding arteries. Others find no such difference. Cf. Quain's *Anat.* ii. 1153.

them in their treatises. Possibly this is only an instance of the very general truth that men, when their mind is strongly occupied by any theory or belief, are able to shut out completely from their view any fact, however obvious to others, that tells against it.

Be this, however, as it may, experiments, such as those of Boyle, afforded so conclusive a demonstration that the necessity of respiration for the maintenance of life could not depend on its refrigerating effect on the blood, that the ingenious arguments of Helvetius and Hamberger failed to find any very general acceptance. And this the more so, inasmuch as a new theory of respiration, against which no such experimental objections could be raised, had been gradually assuming form and consistency, and was now ready to take the place of the discredited doctrine of refrigeration. According to this new teaching, which had however its roots in ancient theories, the key to the problem of respiration was to be found not in the physical properties of the air, such as its temperature or its elasticity, but in its chemical constitution; and the reason why an animal died, or a flame was extinguished, when kept in a limited amount of unrenewed air, was that respiration and combustion either took from the air some ingredient that was necessary for their continuance, or added something to it which brought them to an end.

The similarity of the process of respiration to that of combustion had been, as we have seen, more or less distinctly recognised by Aristotle, Galen, and later philosophers, but the actual identity of their effects upon the atmosphere appears to have been first demonstrated by Mayow, who showed that the alteration which made unrenewed air after a time unfit to maintain the one process made it also unfit to maintain the other; for a flame was immediately extinguished when brought into a receiver under which an animal had been confined until the contained air could no longer minister to respiration. What, then, was this change that the air had undergone? That it was

not a change of temperature, as Aristotle had supposed, Boyle's experiment with a receiver surrounded by ice clearly showed; nor was it a change of elasticity which, said Boyle,[1] was the chief physical characteristic of air, and to which some physiologists were inclined to ascribe its main importance, so far as related to respiration. If, then, the change was not in the physical properties of the air, it must be in its chemical constitution; and this clearly might consist either in something being added to the air by combustion and respiration, that was incompatible with the maintenance of those processes, or in something being subtracted by them from it, that was necessary for their support. It was to this latter view that the English experimenters of the middle of the seventeenth century—such as Hook, Boyle, and Mayow—inclined, though they were far from entirely excluding the supplemental notion that some deleterious effluvium was carried away in expiration. But that the accumulation of such effluvium in the air was the sole or the main cause of its unfitness to support combustion and respiration they would not admit. Apparently they did not take into consideration the possibility that such effluvium might be an invisible aeriform body, such as the *spiritus sylvestris* or *gas sylvestre*, which Van Helmont had stated to be given out in the process of combustion, and also when acid was poured upon certain chalky substances,[2] and the isolation of which, had he been able to effect it, would have made him the discoverer of carbonic acid gas. And thus Boyle apparently thought that he had adequately dealt with the hypothesis which attributed the extinction of flame to the accumulation of some product of combustion, when he had shown by experiment that such extinction

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[1] Cf. *Works*, iv. 90.

[2] 'Acidum stillatitium dum lapides cancrorum solvit, eructatur spiritus sylvestris.' Van Helmont expressly speaks of this gas as invisible, and it was, indeed, because of its obstinately remaining invisible that he called it *sylvestre*. 'Gas sylvestre sive incoercibile quod in corpus cogi non potest visibile' (*De Flat.* 4).

occurred just as certainly though there was no visible smoke to cause it. 'I have found,' he says, 'by trials purposely made that a small flame of a lamp, though fed perhaps with a subtle thin oyl, would in a large spacious receiver expire for want of air in a far less time than one would believe,' and this, he proceeds to say, is not due to 'gross fuliginous smoak,' for the same occurs when spirits of wine, which emit no visible smoke, are used instead of oil. Rejecting, then, the explanation based on a supposed pollution of the air, Boyle strongly inclines to the belief that the necessity of fresh air for the maintenance of a flame depends on the presence in it of some substance 'which enabling it to keep flame alive does yet by being consumed or depraved render the air unfit to make flame subsist'; and later on, assuming this to have been demonstrated in the case of a flame, he extends his hypothesis to respiration and says that 'the necessity of fresh air to the life of hot animals . . . . suggests a great suspicion of some vital substance, if I may so call it, diffused through the air, whether it be a volatile nitre, or rather some anonimous substance, syderial or subterranean, but not improbably of kin to that which I lately noted to be so necessary to the maintenance of other flames.' When Boyle thus wrote, he clearly had not arrived at the conclusion that the substance which was required for respiration, though kin to that required for combustion, was actually identical with it; nor did he think this substance was a constituent part of the air itself, but 'some odd substance solar or astral or of some other exotic nature' intermixed with it. Mayow, however, made a nearer approach to the truth; for he held that the substance which ministered to respiration was identical with that which ministered to combustion, and formed part of the air itself, which was not, as usually supposed, a simple element, but a compound of which one—and this the most active constituent was what he called the igneo-aerial particles, or the nitro-aerial spirit, that is to say the aeriform body, or spirit, that

is given off when nitre is decomposed by heat.[1] It was this nitro-aerial spirit that was the pabulum both of combustion and of respiration.

These views were, it should be said, not absolutely new. Almost invariably, when a discovery has been made, there are found passages in the works of earlier writers, which seem to imply anticipation of the discovery. Such passages, however, rarely, if ever, indicate definitely formed judgments, but merely express passing fancies, unsupported by evidence or reasoning, and in no way detract from the credit of the later and more serious researches. Thus Paracelsus, that fantastic combination of charlatan and man of science, had said[2] long before the time of Mayow that 'as the stomach concocts meat and makes part of it useful to the body, so the lungs consume part of the air, and proscribe the rest.' Of this apparent anticipation Boyle says very justly, 'This opinion is not, as some of the same author, absurd; but, besides that, it should not be barely asserted but explicated and proved.'

The chemical explanation of the processes of combustion and respiration, having been thus fairly started, gained strength and definiteness with each succeeding set of experiments. But to follow out the gradual development of the theory, to show how the doctrine of deleterious products of combustion, and the doctrine of some

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[1] Mayow's proof, in his little treatise *De Sal-nitro et Spiritu Nitro-Aereo*, that the igneo-aerial particles of air are also a constituent of nitrous spirit is as follows. Sulphur will burn under a jar full of air, but will not burn if the air has been removed from the jar by the air-pump. But it will readily burn in the exhausted jar if mixed with nitre. The nitre clearly supplies something which the air supplied before. If nitre be decomposed by heat, an aeriform substance or nitrous vapour is given off, and a solid substance remains behind. This solid substance, if mixed with sulphur, does not enable it to burn in the exhausted jar. The something, then, supplied by nitre must be contained in the nitrous vapour.

[2] I make this quotation on the authority of Boyle (*Works*, i. 107), but have been unable myself to find the passage in the labyrinth of the writings of Paracelsus.

necessary substance contained in the air, became fused together, and how the noxious product and the essential air constituent were successively isolated and examined, and were christened respectively as carbonic acid and oxygen, would be beyond the scope of this introduction. For our present purpose the point of interest is to note that the doctrine to which Aristotle's theory had eventually to succumb was in reality a development of ancient views with which that theory had successfully contended through a long series of centuries; for the doctrine of air rendered unfit for combustion or respiration by the product of those processes themselves takes us back to Galen with his *fuligo* and his *ustæ materiæ superfluitas*, while the doctrine of a necessary substance supplied by the air takes us still further back to the pre-Aristotelian surmise that the air served in some unexplained way as the pabulum of fire.[1]

The theory, then, which based the necessity of respiration on the necessity of blood refrigeration was swept away by the rising tide of chemical knowledge. There still, however, remained the question, does the supposed refrigeration, whether useful or not, as a matter of fact occur at all? Is the blood that has passed through the lungs colder than that which comes to them? That heat is constantly being lost in expiration is an obvious fact, and it was a natural inference that the heat thus lost was derived from the pulmonary blood, which thus became cooler. It might, however, be that this loss was compensated and masked by the development of fresh heat in the lungs themselves, and that such was the case was the opinion of Haller,[2] and was held very generally in that later period when it was supposed, on the authority of Lavoisier, that the lungs were, so to speak, the fireplace of the system, inasmuch as it was in them that the oxygen of the inspired air combined with the carbon of the body.

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[1] See p. 27.

[2] *El. Physiol.* iii. 345-6.

But when it had been shown that this part of Lavoisier's teaching was erroneous, the question again became open to discussion; and physiologists returned to the earlier view, and again held that the blood was cooled in its pulmonary transit, partly by directly warming the inspired air, and partly by supplying heat for the abundant evaporation of fluid. Nor was this merely an *a priori* inference from the greatly increased moisture and heat acquired by the air during its sojourn in the air-passages, but was an opinion supported by direct experiments, and notably by those of G. von Liebig[1] and Claude Bernard,[2] who found that the blood in the left cavities of the heart was perceptibly colder than that in the right ventricle. These results have, however, not been unchallenged, and among those who have called them in question may be mentioned Sir William Savory,[3] who pointed out serious defects in the conditions under which the experiments had been made, and came to the conclusion from his own experiments, that, when these defects are avoided, it is found that the blood, so far from being cooled in the passage through the lungs, becomes slightly heated, the extra heat being derived, we must suppose, from a certain amount of combustion going on in the pulmonary tissues and vessels, as in the other parts of the body. Very much the same results were obtained ten years later by Professor Colin of Alfort.[4] For this physiologist found, as the outcome of an extensive and careful series of experiments upon various animals, that though the change undergone by the blood in its transit from the right to the left side of the heart is very far from constant, yet much the most common alteration, and that which must be regarded as the normal occurrence, is a slight rise of temperature. If we accept these results as

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[1] *Uber die Temp. des ven. und art. Blutes.* Giessen, 1853.

[2] *Comptes Rendus*, 1856, Sept. 15.

[3] *On the relative temperature of arterial and venous blood.* London, 1857.

[4] *Ann. d. Sciences Nat.* 1867, sér. v. t. 7, p. 83.

final—and there seem no adequate grounds for doing otherwise—the last vestige of Aristotle's doctrine of refrigeration will have disappeared ; for it will have been shown that not only is such refrigeration unnecessary, but that, as a matter of fact, it does not occur.

ON YOUTH AND OLD AGE, AND ON LIFE AND DEATH

(*Ch.* 1.) Let us now treat of Youth and Old Age and of Life and Death; with which subjects we may perhaps find ourselves compelled to combine that of Respiration and its causes; for it is on respiration that, in some animals,[1] life and death depend.

Our views concerning the soul have been set forth elsewhere;[2] and it has been shown that, though the soul cannot be itself corporeal, yet it manifestly has its seat in some special part of the body, and this a dominating part.

Now, of the various parts or faculties of the soul—whichever may be the proper term by which to designate them—the only ones with which we need now concern ourselves are those which belong to all such living things as possess not only life but animality. For, though an animal must necessarily be a living thing, living things are by no means of necessity animals; for plants live, and yet are without sensation, which is the distinctive characteristic of an animal. And the part in which is lodged that faculty of the soul in virtue of which a thing lives must also be the part in which is lodged that faculty in virtue of which we call it an animal.[3] The part, that is, must be actually one and the same,

467, b, 25 [1] For Notes, see end of Text, p. 107.

though ideally multiple and diverse; for to live and to be an animal are diverse things. And this part must lie in the centre between the anterior and posterior aspects of the body; for such is the position of the sensorium commune, or the one general meeting-place to which are conducted the motions from the several organs of special sense. By anterior is meant the direction in which the senses operate,[4] and by posterior is meant the opposite direction.

Again, the part must be midway between the upper and the lower halves of the body. For the body of every living thing, be it an animal or a plant, may be divided into an upper and a lower portion, and the seat of the nutritive faculty must manifestly be in the middle between these two.[5] By upper is meant that part which contains the orifice for the admission of food; and we speak of this as upper with reference to the body itself, and not with reference to the encompassing universe. By lower we mean that portion of the body which contains the excremental vent.

There is a great contrast in this matter between plants and animals. For in man, and in man alone, owing to his erect attitude, the upper part of the body is turned towards the upper part of the universe;[6] while in other animals it is turned neither to this nor to the lower aspect, but in a direction midway between the two. But in plants, that are fixed to the earth and derive from it their nourishment, the part by which they imbibe nutriment, that is, their upper part, must of necessity always be placed downwards.[7] For the roots of

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plants are analogous to what is called the mouth in an animal, being the organ by which food is admitted,[8] and in the case of plants the food is derived from the earth [*either directly*] or through the intermediation of plants themselves.[9]

(*Ch.* 2.) The body of every perfect animal is divisible into three parts, namely one by which food is taken in, one by which excrement is discharged, and a third which is placed between the two others. This last is in the larger animals called the chest, while in the smaller it may have no special name; it is, moreover, much less distinct in some animals than in others.

Such animals, again, as are capable of progression have also other additional parts that minister to this office, namely the legs and feet, or parts equivalent to these, which serve for the transport of the whole trunk.

Now it is in the central of the three parts, above distinguished, that the nutritive principle has its seat, as is not only demonstrable by rational inference but is visible to the senses. For in many cases either the upper part, that is the head, or the lower part, that is the receptacle of the food, may be cut off and yet life be maintained by the remaining extremity which is still in connection with the central part.[10] This phenomenon is very conspicuous in the case of insects, such as wasps and bees; but there are also many animals,[11] other than insects, that are able to retain vitality after their body has been cut in pieces.[12] This they can do because their nutritive principle, though actually one, is potentially multiple, their constitution in this resembling that of plants.

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For the separate segments of a plant retain vitality after subdivision, and a single tree can thus give rise to many. While, however, the segments of a plant can live on indefinitely, this is not the case with the segments of an animal. For such segments are without the organs necessary for the maintenance of life, being destitute some of a mouth for the prehension of food, some of a stomach for its reception, and some of both of these parts and of others besides.[13]

As to the reason why slips can be taken only from some plants, while the rest cannot be propagated by subdivision, that is a question to be discussed elsewhere.[14] But in this respect at any rate plants and animals resemble each other; for only some animals can live after division of their body. Such animals resemble an aggregate of individuals fused together by growth.[15] But in animals of the most perfect constitution such subdivision with retention of life is impossible; for in them the organisation has reached the highest degree of unity.

It follows from what has been said that in insects[16] the nutritive principle, though actually one, must be potentially multiple. And the same is true also of the sensory principle; for the separated segments of the animals in question plainly retain some sensibility.[17] Some of them also even make feeble movements,[18] showing that they are still subject to some psychical influence. For the trunk moves after the viscera have been extracted,[19] or even, as in tortoises, after the heart has been removed.

(*Ch.* 3.) However, that the main seat of the nutritive soul is central is plainly to be seen both in plants and in animals. In plants it is manifested in
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the phenomena presented by the germination of seeds and by grafts and cuttings. For invariably the development of a seed proceeds from a central spot. For all seeds consist of two valves,[20] which are joined together [21] at the point where the seed is connected with the mother-plant; and it is from this point as a centre, which belongs equally to either side, that both stem and root are given off when growth begins; for it lies midway between them, and gives origin to both.[22]

In the case of grafts and cuttings, it is the eyes or buds that are the main seats of growth; for it is from one of these that each branch originates, as being a centre of development. It is therefore the eyes or buds that the gardener takes for his cuttings or inserts as grafts,[23] in order that branch or roots may spring from them, as being centres that can give rise to both.

Again, in such animals as have blood, it is the heart that is the first part to be formed, as we have ourselves seen in those cases where we were able to observe the growth of the embryo.[24] And what is true of the heart in sanguineous animals cannot but be also true of the part that corresponds to a heart in bloodless animals.

It has already been stated in the treatise on the Parts of Animals [25] that the heart is the centre from which the blood-vessels spring, and that the blood is in sanguineous animals the ultimate nutriment out of which the parts are formed. It is manifest, therefore, that though one operation in regard to the reduction of the food is performed by the mouth,[26] and a second part in the same business falls

to the stomach, it is the heart on which the highest duty devolves, and that effects the final elaboration.

It follows then of necessity that it must be in the heart that the nutritive soul (as also the sensory) has its central habitation. For as regards nutriment, the offices of the other organs are ancillary to the office of the heart; and that must be the dominating organ in which the final result is achieved rather than any of those that are subservient to merely preparatory processes, as a physician who restores health is above the subordinates who supply him with materials.

Again, the presiding seat at any rate of sensation is in all sanguineous animals in the heart, where all the organs of sense have their common sensorium. Two of the senses, namely taste and touch, are manifestly connected with the heart, and from this we may infer that the same is the case with the others. For the organs of these other senses can communicate their motion to the heart, while taste and touch show no connection with the upper region [*that is with the brain*].[27]

Besides this, if that which gives life be lodged in all animals in the heart, it is plain that there also must be lodged the sensory principle; for the principle in virtue of which an animal has life is, in our view, inseparable from that in virtue of which it is an animal; and this latter is, according to us, the sensory principle.[28]

As for the reason why some of the senses are in manifest connection with the heart, while the rest are situated in the head—a fact which has led some persons to suppose that the brain is the organ of

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sensation—[29], this is a question which has been discussed separately elsewhere.[30]

The evidence of facts, then, as stated above, clearly demonstrates that the main seat of the sensory soul, as also of that which is concerned with growth and nutrition, is in the central of the three parts of which the body is composed; (*Ch.* 4) and the same conclusion may be drawn by rational inference from the observed law that out of possible arrangements nature invariably adopts that which is most advantageous. For, by the soul with its several faculties being placed in the centre of the body, each part will be best enabled to perform its office, whether it be the part in which the nutriment is finally elaborated or that which is its recipient. For, when so placed, the soul will stand in nearest relation to both.[31] Moreover, a central position[32] is that which is most appropriate for a ruling power. Nor should the instruments and the user of the instruments be without distinction of place. For, as they are separate in function, so, when possible, they should have separate location, as the hand is separated in space from the flute on which it plays.

The sensory faculty, then, which is the distinctive characteristic of an animal, must in sanguineous animals be lodged in the heart, and in bloodless animals in the analogous organ.

So also is it as regards natural heat. For the body of every animal, and each of its several parts, possesses a certain innate natural heat, so that during life they are sensibly warm, but become cold when life departs and death ensues. Now, the fountain-head of this heat must in sanguineous animals be of neces-

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sity in the heart, and in bloodless animals in the analogous organ; for the elaboration and concoction of the food, though carried on in all parts[33] by the agency of their natural heat, is especially effected in the dominating organ, that is in the heart or its analogue.

Thus it is that all the other parts of the body may become cold, and yet life be maintained; but, if this happen to the heart, there is no escape from destruction, inasmuch as the heart, or, in bloodless animals, that which takes the place of a heart, is the primal source of heat and the residence of the soul, which is, so to speak, embodied there in fire.

The maintenance, then, of this fire and the maintenance of life are of necessity identical, and its destruction is what is known as death.

(*Ch.* 5.) Now there are two ways in which fire[34] outside the body can, as we see, come to an end, namely, exhaustion and extinction. By exhaustion we mean that termination which is produced by the fire itself; by extinction, that which is produced by the contraries of fire [*that is by cold and fluid*].

Of these terminations, the former is brought about [*within the body*] by old age,[35] the latter by external force. Both endings are, however, due to one and the same cause [*namely lack of fuel*]. For cold arrests the process of concoction [*in the stomach*], and so prevents the fire in the heart from being duly fed; and, when the fuel fails and the heat can no longer obtain its necessary sustenance, it comes to an end. Exhaustion, too, is brought about by heat accumulating in excess, owing to deficient respiration, and, consequently, deficient refrigeration. And such excess of heat, equally with cold, causes the fuel to

469, b, 30

fail ; inasmuch as it consumes this so rapidly, that it is used up before a fresh supply can rise by exhalation [*from the stomach*].

Thus not only does a large fire cause exhaustion of a smaller fire,[36] but the flame of a candle is destroyed when placed in a greater flame ; for this consumes the lesser flame as it would any other combustible substance, seizing its contained fuel and using it up, before a fresh supply can rise to the wick. For fire is like a river, ever flowing away, and ever being formed anew, though the substitution is so rapid as to elude observation.

It is evident, then, that if the heat is to be maintained—and such maintenance is a necessary condition of life—there must be some provision for the refrigeration of that which is in the central heart.

We may illustrate this from the phenomena presented by the coals in a chafing-pan,[37] when the cover is shut down. For if this be kept down continuously, the embers are soon extinguished ; whereas, if it be put on and taken off in frequent alternation, they will remain alive for a considerable time. Merely covering the fire with ashes keeps it alight ; for the ashes on the one hand offer no hindrance to transpiration, inasmuch as they are of a porous character, and, on the other hand, prevent the external air from extinguishing the fire by its opposite excess of cold.[38] This difference, however, in the results of covering the fire with ashes and covering it with a close couvre-feu is a subject that has been discussed in the Book of Problems.[39] The one process exhausts the fire, the other allows it to remain alight for a considerable time.

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(*Ch.* 6.) Inasmuch as everything that lives[40] has a soul, and the soul, as has been already set forth, cannot subsist without natural heat, there must in all living things be some provision to protect this heat from exhaustion. Now in plants the refrigeration that is effected by food and by the surrounding medium is sufficient for the purpose. For food, no less than air, when it is first taken in, causes refrigeration; and this is true even in the case of man. Fasting, on the other hand, causes heat and induces thirst. For air, if it remain without motion, always becomes heated.[41] But the admission of food moves the air, and cools it, until such time as the food has been concocted.

The natural heat of plants, then, is adequately guarded under ordinary conditions; but, should the medium in which they are living become excessively cold, owing to the occurrence of severe frosts in winter, they shrivel up; and, similarly, should intense heat prevail in the summer, and the fluid absorbed from the soil be unable to produce refrigeration, the natural heat of trees is brought to an end by exhaustion; and in such seasons they suffer from what is called star-stroke and blighting. It is to prevent this that gardeners cover the roots of plants with certain kinds[42] of stones or with pans of water, that they may be kept cool.

As regards animals, some of whom are aquatic while others are terrestrial, it is the medium in which they are living, water or air as the case may be, that supplies the means of refrigeration; and how this is effected we must now explain, interrupting our discourse for this purpose.

470, b, 5

ON RESPIRATION

(*Ch.* I.) The subject of respiration has been handled by several of the old physicists, but not by many. Some of those, moreover, who have dealt with the matter have said nothing whatsoever as to the purpose to which the process is subservient in an animal's body, while the rest have treated of this, but erroneously and without due cognisance of the facts. Moreover, they assert that all animals respire, which is far from being the case.[43] As, however, we would not be thought to be misrepresenting men who are no longer here to defend themselves, our first business must be to give a fuller exposition of the statements of these writers.

So far, then, as concerns those animals that have a lung, it is manifest that they all breathe. Not but that even among these there are differences. For those of them whose lung is poorly supplied with blood and of spongy texture have comparatively little need of respiration, and are consequently able to live without breathing for a considerable time, the duration of which depends upon their bodily strength. The lung is of this spongy character in all the ovipara,[44] as, for example, in frogs. So also is it in tortoises and Emydes,[45] and these animals can therefore remain under water for a long time.[46] For their lung has but scanty heat, inasmuch as it has but scanty blood; when, therefore, it has once been inflated, it produces [*adequate*] refrigeration by its own motion,[47] and thus enables the

470, b, 21

animal to live without further respiration for a considerable period.

Even these animals, however, are eventually suffocated, if they be held forcibly under water for too long a time; for no animal of this kind takes in water after the manner of fishes. Those animals, on the other hand, whose lung is rich in blood have much greater need of respiration, because of their much greater heat. There remain the animals that have no lung, and of these there are none that breathe.[48]

(*Ch.* 2.) Now Democritus of Abdera and some others of those who have treated of respiration have not spoken very definitely as to these lungless animals, though their words seem to imply a belief that all animals alike respire. Anaxagoras, however, and Diogenes distinctly state that such is the case, and, as regards fishes and oysters, give an account of the manner in which, according to them, respiration is effected. What Anaxagoras says is that when the water is discharged by a fish through its gills air takes its place in the mouth, inasmuch as there is no such thing as a vacuum, and that the fish sucks this air in, and so respires; while Diogenes says that, when the water is discharged, a vacuum is formed in the fish's mouth, and that air is drawn in by the action of this vacuum from the water that environs the fish's head, the water, according to his view, containing air.[49] But these accounts cannot possibly be true. For in the first place these writers entirely leave out one half of the matter; for what they say applies not to respiration in its wider sense, as embracing the whole process, but to respiration

471, a, 7

in its narrower sense, as applied to one part only of the process, namely, to inspiration. For respiration is made up of inspiration and of expiration; and concerning this latter, and the mode in which it is effected in the animals in question, neither of them says a word. Indeed, there was nothing they could possibly say. For when an animal has inspired air, it must discharge this again by the same channel as that by which it was taken in,[50] and inspiration and expiration must go on in constant alternation. Either, therefore, the fish must expire the air at the very same time as it is admitting water into its mouth, in which case the ingoing water and the outgoing air would meet and impede each other; or the expiration must occur, be it by mouth or gills, at the time when the water is being discharged from these latter, in which case inspiration and expiration would occur simultaneously, for this is the very time when, according to them, the fish inspires. But that inspiration and expiration should occur simultaneously is impossible. Inasmuch, therefore, as respiration involves expiration as well as inspiration, and inasmuch as none of the animals we are considering can possibly expire, it follows that none of them can breathe.

(*Ch.* 3.) Moreover, to say that a fish extracts air from the water by means of its mouth, and then draws it in out of that cavity, is to maintain an impossibility. For a fish, having no lung, has in consequence no windpipe, its stomach coming immediately behind its mouth. Any drawing in of air would therefore have to be done by its stomach. But if the stomach has this power, other animals

471, a, 24

would use it in the same way, which is not the case. Fishes themselves, moreover, would be seen so acting when taken out of the water; but they plainly do nothing of the kind.

Again, in all animals that respire and draw in breath we see a certain motion occurring in that part of the body by which the drawing in is effected. But no such motion is observable in fishes in the region of the stomach; the only movement that can be seen being in the gills, and this whether the fish be in the water or lie gasping on the bank.

Again, when any animal that can breathe is suffocated under water its breath is expelled with force and forms bubbles. This is the case, for instance, when tortoises or frogs are held under the surface. But with fishes—vary the form of the experiment as you may—nothing of the kind occurs, which implies that no external air has been inhaled.[51]

Moreover, if fishes could respire in the way these writers say they do, men also should be able to do the same when under water. For why should not men and other animals be able, just as much as fishes, to draw air into their mouths out of the water about them, and again draw this out of their mouths? If it were possible in the one case, it would be possible in the other. But as it is impossible for man, so also manifestly must it be impossible for fishes.

Still further, if fishes breathe, how comes it that, when they are pulled out of the water and kept in the air, we see them gasping, just like animals that are being choked, and eventually dying?[52] For most assuredly it is not because the lack of water is

471, b, 14

a lack of sustenance that they are thus affected; and as for the reason assigned by Diogenes, it is simply foolish. He says that the fish dies in the air because, when there, it takes in too much of it; whereas when in the water it only takes in a moderate amount. But if this were so, land animals also should be liable to a similar affection; but, as a matter of fact, no land animal is ever choked by an excess of breath.

Again, if all animals breathe, then insects, being animals, must do so. Now many insects, as for instance those known as Scolopendra, can live after they have been cut in two; or even when they are not merely cut in two but divided into numerous bits. Now how can these divided insects breathe, and by means of what organ?

The main cause of these erroneous statements was the ignorance these writers were in as to the internal organs, and the fact that they had not grasped the truth that nature in all her works has a final cause in view. For had they put the question to themselves, what is the purpose for which respiration exists, and had they sought for an answer by investigating the parts of the animal body, such as the gills and the lungs, they would soon have hit upon the right explanation.[53]

(*Ch.* 4.) Democritus, it is true, does ascribe a certain consequence to respiration; for he says that it prevents the soul from being pressed out of the body. He by no means, however, says that nature, in giving respiration, had this purpose in view; for, like the rest of the Physicists, he has no conception of such a thing as a final cause. What he says is

472, a, 3

that the soul and heat are one and the same thing, being the primary forms of spheroids, and that when these are being expelled by the pressure of the environing medium, respiration comes to the rescue.[54] For that in the air there are a vast number of those spherical atoms which he identifies with mind and soul; and that, when the animal inspires, and the air enters in, these spheroids enter with it, and by counteracting the pressure prevent the soul from quitting the animal's body. This, he says, is the reason why life and death are determined by inspiration and expiration. For when respiration is obstructed, so that the outer air can no longer get in and counterbalance the pressure of the surrounding medium, the animal forthwith perishes; death being, in fact, the departure from the body of these spheroid forms, which have been driven out by the pressure of the environment.

As for any conceivable reason why death should necessarily come to all animals; or why, allowing that it must come, it should not come indifferently at any period of life, but only come in old age (that is supposing the death to be natural and not due to violence), not a word of explanation is offered by Democritus. And yet, seeing that natural death occurs only at one period of life and not indifferently at all, some explanation was wanted, and we ought to have been told whether the cause was something acting from without the body or something acting from within. Again he says nothing whatsoever as to the cause by which respiration is initiated, and whether this also is something acting from without or something acting from within. The starting-

472, a, 22

point, however, of respiration, and of the motion that accompanies it, must be something internal; for it cannot be that the external mind watchfully provides the supposed assistance to the internal mind, by forcing the environing air to make its way in. Strange too does it seem that the environing medium should at one and the same time cause the destructive pressure and by its entrance cause the counteracting expansion.

Such then is the account given by Democritus, and such pretty nearly are the words in which he has expressed himself.

Let us now assume that what was stated a little way back is true, and that only some animals, and not all, respire. In that case the explanation of death, as given by Democritus, must be taken as applicable not to all deaths but to the deaths of those animals only that breathe. But in reality it is not applicable even to these, as is plainly shown by phenomena and facts with which we are all familiar. For in sultry weather, when our bodies are more than usually hot, we all have greater need of respiration and breathe with increased rapidity. On the other hand, when we are in a cold environment, which contracts and congeals our bodies, we hold our breath;[55] and yet, if the view of Democritus were true, this is above all other the time when the outer air should be admitted and prevent the expulsion of the spherical atoms by pressure. What really happens is just the opposite. For it is when heat has accumulated in excess, owing to its not having been discharged by expiration, that the need of respiration is most urgent, and the inhalation of

472, b, 3

air most necessary. And the reason why men breathe so rapidly when they are hot is that the purpose of respiration is to cool the body ; whereas, if Democritus were right, this more rapid breathing would simply be adding fire to fire.

(*Ch.* 5.) As to the pushing-round process described in the Timæus,[56] we are not told whether the same process goes on in all animals alike, or whether in animals that are not terrestrial there is some other method by which the preservation of the heat is effected.[57] And yet, if respiration be peculiar to land animals, we ought to be told why they are thus specially distinguished ; and if, on the other hand, aquatic animals are also able to breathe, but after some different fashion, this also should have been clearly explained to us.

Moreover the proposed explanation of the process of respiration is purely fantastical. For the account given is that, when the hot breath is discharged by the mouth, the surrounding air is thrust forward by it, and being carried on by the impulse is made to pass through the porous surface of the body until it occupies the same place as that from which the hot air had issued, the replacement being determined by the impossibility of a vacuum ; and that this air in its turn, when it has become heated, passes out again by the same channels as had given it admission, and impinging on the air that had previously been discharged in a hot condition through the mouth, drives it back again through that orifice to the interior space ; and that thus a continuous alternation of inspiration and expiration is kept up. According to this view, expiration must be anterior to inspiration ;

472, b, 21

whereas the contrary can be shown to be the case. For inspiration and expiration are inseparably associated processes, and as expiration is the final one of the two—for those who die expire—inspiration must necessarily be the first of them.

Again, those who give this account of respiration say nothing whatsoever as to any purpose to which inspiration and expiration may be subservient in the animal body, but deal with the whole process as a mere incidental result; and yet life and death are absolutely dependent upon it, as we plainly see; for, when any animal that breathes is prevented from so doing, it forthwith dies.

Again, it seems extraordinary that the discharge of the hot air by the mouth and the re-entrance of the air by the same channel should be plainly visible to us, but that the entrance of the breath through the pores into the thorax and its discharge thence when heated should be quite imperceptible.

Nor less strange is the statement that hot matter is introduced by inspiration; [58] for, according to all appearances, the very opposite is the case, seeing that the air when expired is hot, while the inspired air is cold. Moreover, in hot weather animals pant when breathing; for they are obliged to draw breath frequently because the air that is inhaled does not cool them sufficiently.

(*Ch.* 6.) Neither can we possibly accept the idea that the purpose of respiration is nutritive, meaning thereby that the internal fire is fed by the breath; [59] and that inspiration is, as it were, the throwing of fuel on a furnace, while expiration is the blast of hot air that follows on such feeding of the fire.

473, a, 6

To this supposition we make the same objection as to those previously discussed, namely that, were it true, the same process, or an analogous process, ought to occur in all animals; for all animals have vital heat. Moreover, in what sense are we to understand this fantastical notion, that heat is generated out of the breath? For it is out of food rather than out of air that we see heat developed. Again the supposition implies that the nutritive matter and its residue are admitted and discharged by one and the same opening, which is quite opposed to all analogy.[60]

(*Ch. 7.*) The subject of respiration has also been dealt with by Empedocles. But he, like the rest, says nothing as to its use, nor states clearly whether he supposes all animals to breathe or only some. Moreover, when he is only speaking of the passage of air through the nostrils, he imagines that he is dealing with the essential process of respiration. But, besides the passage of air through the nostrils, there is also the passage of air through the windpipe to and from the chest, and the nostrils by themselves without the windpipe cannot possibly inspire. Indeed the passage of air through the nostrils may be entirely stopped and the animal be no whit the worse; but, when the air is prevented from passing through the windpipe, the animal dies.

The passage of air through the nostrils is not, however, without its end. For in some animals nature uses it for a bye-purpose, namely, to minister to the sense of smell.[61] I say in some animals, for, though nearly all animals have the sense of smell, they do not all smell with the same organ. This,

473, a, 27

however, is a subject which has been dealt with elsewhere in greater detail.[62]

Empedocles explains inspiration and expiration in the following way. He says that there are certain vessels that contain blood, but not in such amount as to fill them. These vessels communicate with the external air by pores, which are too small to give passage to the particles of blood, but large enough to give passage to those of air. Now, it is the nature of blood to move to and fro,[63] and when it moves downwards the air flows in and inspiration occurs; but when, on the other hand, it moves upwards, the air is driven out, and expiration is produced. This process he illustrates by comparison with a clepsydra, as follows [64] :—

Thus all breathe in and all breathe out. In all
Are tubes, unfilled by blood,[65] that through the flesh
Stretch surface-wards, to where the projecting nose [66]
Is tunnelled through with close-set[67] passages.
In these have they such openings as give
Free pass to air, but keep the gore confined.
When inwards from the surface ebbs the blood,
Tempestuous air with eager wave flows in,
Again to be expelled, with course reversed,
When turns the tide. So, when some girl at play,
Taking a bronze clepsydra [68] for her toy,
Blocks up with shapely hand its open tube
And dips [69] the vessel 'neath the silvery sheen
Of limpid water, not a drop of this
As yet makes entrance; for the air within,
Pressing with force upon each orifice,
Forbids all ingress, till the girl withdraws
Her hand, when straight the yielding air gives way
And in its stead flows in an equal stream.
Now is the vessel full; the girl, again,
Blocks with her palm [70] the bronze-wrought pipe, and now
The outer air, besieging all the pores,

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Forbids the imprisoned flood to percolate
With pattering drops the strainer's [71] openings,
Till the child lifts her hand. Then the strong air,
Conquered before but now the conqueror,
Inrushing through the tube, drives out the stream
In headlong rout before it through the pores.
So when the thin [72] blood, coursing through the limbs,
Retires with ebbing stream to inner depths,
Straightway the air flows in with surging wave,
Again to hurry forth, with equal force
Of expiration, when the blood rebounds.

Such, then, is the account of respiration given by Empedocles. Now, all animals that visibly respire breathe, as we have already stated, through the windpipe, the air passing in by the mouth and at the same time by the nostrils. If, then, this respiration through the windpipe is that of which Empedocles is speaking, we must examine how far his account of the process harmonises with the visible phenomena; and it is manifest that it is far from so doing. For, when an animal makes an inspiration, the part into which the air passes is expanded, like the bellows in a smithy. This expansion [*is quite unexplained by the theory of Empedocles, but*] is reasonably attributable to heat or to the blood which acts in virtue of its heat. Similarly, when the animal expires, the part falls in and collapses, again like the smith's bellows. There is, however, this difference. The air in the bellows is not admitted by the same orifice as that by which it is discharged, whereas one and the same channel serves alike for inspiration and for expiration.

But if Empedocles is not speaking of respiration through the windpipe, but only of the passage of air through the nostrils, his account is very wide of
474, a, 18

the mark. For respiration is not a process confined to the nostrils, inasmuch [*as some of the air is transmitted, not by these passages, but by the mouth, and inasmuch, moreover,*] as the air which has entered by the nostrils passes through the narrow passage[73] which is close to the uvula, at the far end of the arched roof of the mouth, there being openings that connect this part with the nostrils; and the air which enters and issues by this passage, and the air which passes directly by the mouth, together make up the inspiration and the expiration.

Such, then, and so great are the difficulties that present themselves in the accounts of respiration given by previous writers.

(*Ch.* 8.) It has already been stated that life and soul require for their presence a certain heat.[74] For not even concoction, by which food is converted into nutriment, can be effected either without heat or without a soul; for it is by fire that all such operations are wrought. It follows, therefore, of necessity that the same primary region of the body, and the same primary part of that region, which is the necessary seat of this principle of heat, shall also be the seat of the primary or nutritive soul. And this region is that which lies midway between the part by which food is taken in and the part by which the residue is voided. Now, in the bloodless animals this portion of the body has no name, but in animals that have blood it is called the heart. For the nutriment out of which the parts of animals are directly formed is the blood, and the blood must have the same centre or starting-point as the blood-vessels, for blood and vessels exist for each other,

474, b, 7

the vessels being receptacles to hold the blood. But the centre or starting-point of the vessels, in all animals that have blood, is the heart, for the vessels do not merely traverse the heart, but originate in it, as we see clearly on dissection.[75]

The nutritive soul, then, must be seated in the heart, for it cannot possibly subsist apart from the vital heat, for nature has embodied it in this fiery substance; and as the other faculties of the soul cannot possibly subsist apart from the nutritive, for reasons that have already been set forth in the treatise on the soul, they also must be located in the heart.[76]

Now fire, as has previously been stated,[77] may come to an end in two ways, either by extinction or by exhaustion. Extinction is suppression by a contrary. Fire, then, can be extinguished by cold in the environment, and this in mass, though the extinction is more rapid if the fire be previously scattered. Now, to this violent termination living things, as well as lifeless things, are liable. For animals are killed by congelation from excess of cold, and the more rapidly if the animal be first cut in segments.[78] Exhaustion, on the other hand, is from excess of heat. For if the surrounding heat be excessive, and the fire be not fed, the combustion comes to an end, not from cold, but from exhaustion.[79] Against such a termination refrigeration is a safeguard; and, therefore, if animals are to be secured from it, they must of necessity have means of refrigeration.

(*Ch.* 9.) Now some animals are aquatic, while others live on dry land; and of each kind there are

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some that are excessively small and bloodless. To such the refrigeration that is brought about by the environing medium, be this air or water, provides an adequate security against death from excess of heat;[80] for, inasmuch as they have but little heat, they require but little provision against its excess. It is owing to this paucity of heat and absence of blood that such animals[81] are almost invariably short-lived, for a very slight change on either side suffices to upset the balance.

Among insects, however, though they are all destitute of blood, there are some that have a longer span of life. In such there is a fissure below the waist,[82] and the membrane that covers this fissure is thinner than elsewhere, so that refrigeration may occur through it. For such insects, having more heat, require more perfect provision for refrigeration. Among these insects are bees[83]—for some bees live as long as seven years[84]—and such other insects as make a humming noise; for instance, wasps, cockchafers, and cicadæ. For the sort of panting sound made by these insects is produced by the innate spirit within their bodies,[85] which, by the rise and fall which it occasions, causes friction against the membrane at the junction of trunk and abdomen. For there is a motion of this part in insects, like the motion brought about by the lung in animals that breathe the outer air, or by the gills in fishes. This movement is closely analogous to that which occurs in any animal that breathes, when it is choked by holding its mouth under water; for a similar heaving of the chest is brought about under such circumstances by the lung./ But, whereas in animals that

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breathe, this kind of motion[86] does not produce adequate refrigeration, in insects it is sufficient for the requirements.

It is, then, by friction against the membrane that insects produce the sound[87] which we term humming; just as children produce a sound by blowing through a reed, in which they have bored a hole, and covered it with a thin membrane. The cicadæ also, such cicadæ that is as sing, produce their song by means of a similar membrane. For these cicadæ are hotter than their fellows, and have a fissure below the junction of trunk and abdomen, whereas there is no such fissure in those that are unable to sing.[88]

Among those animals that have blood[89] and possess a lung, there are some that can live for a long time without breathing. These are those whose lung is of a spongy texture and contains but little blood or fluid, in consequence of which it admits of great expansion.[90] For its own proper motion enables it to produce sufficient refrigeration for a considerable time.[91] There is, however, a limit to its power, and such animals, if prevented from breathing, are eventually suffocated, as was said before. For suffocation is the term applied to exhaustion by lack of refrigeration; and animals that so perish are said to be suffocated.

It has already been stated that insects are not animals that breathe; and this is manifest in the small kinds such as flies and bees. For, if such insects be immersed in any fluid, they swim about in it for a considerable time, unless the fluid be excessively hot or excessively cold; and yet animals

475, b, 2

with small strength as a rule require more frequent respiration. Eventually the fly or bee perishes, from what is called suffocation, because its belly gets so drenched that the membrane [92] at the junction of the trunk and the abdomen is rendered perfectly useless. This explains why the insect recovers itself, if it be put for a time to lie in the warm ashes.

Again, of aquatic animals, those that are bloodless live longer when removed from their element and exposed to the air than do those that have blood and that take in the sea-water after the manner of fishes.[93] For, inasmuch as they have but little heat, the air suffices for their refrigeration for some considerable time; not but that in the end it proves inadequate to maintain their vitality.

The Malacostraca [*crustacea*] and the poulps [94] are instances, for these are animals with little heat. [*Nor need we be surprised at this ;*] for even fishes are frequently [95] found underground, and when dug up are still living, though in a motionless condition. For animals that are entirely without a lung, or that have a lung that is deficient in blood, have comparatively infrequent need of refrigeration.

(*Ch.* 10.) We have now dealt with the bloodless animals, and have pointed out how to some of them the surrounding air, and to others the surrounding water, supplies the requisite aid for the maintenance of life. But of animals with blood, and that possess a heart, all those that also have a lung take in air, and effect their refrigeration by means of inspiration and expiration. And those have a lung that are viviparous; that is to say, that are internally viviparous and not merely externally; for the Selachia

475, b, 21

are viviparous, but not internally.[96] Again, among the Ovipara, those have a lung that have wings, as birds ; and those also that have scaly plates, as tortoises, lizards, and snakes. But in the former, that is in the Vivipara, the lung is rich in blood, while in the latter, that is in the Ovipara, it is in most cases[97] of a spongy character, on which account,[98] as was said before, these animals have less constant recourse to respiration. They do, however, respire, as do all animals that have a lung, even those that spend their lives habitually in the water, as for instance water-snakes,[99] frogs, crocodiles, fresh-water tortoises,[100] and those that inhabit the sea, and not only such as live on land, and seals. For all these animals, and others that resemble them, though they produce their offspring on land,[101] sleep indifferently on land or in the water, keeping in the latter case their head above the surface, so as to be able to breathe. On the other hand, all animals that have gills are refrigerated by the admission of water. Such is the group of animals known as Selachia,[102] and such are other apodous animals, among which are included all fishes ; for the appendages of fishes are not feet but after the fashion of wings.[103]

Of animals with feet there is but one that has a gill among all such as have come under observation,[104] namely the animal known as a tadpole ;[105] and no animal has yet been seen having at the same time lung and gills.[106] And the reason is, that the lung exists for the purpose of refrigeration by air (whence seemingly its name in Greek ; *pneumon* meaning lung, and *pneuma* the air which it takes in), and the gills exist for the purpose of refrigeration by

476, a, 10

water. But for a single purpose it is well to have a single instrument, and in all cases one mode of refrigeration is sufficient. Since, then, nature, as we see, makes nothing in vain, and since, were there two instruments of refrigeration, one of them would be to no purpose, some animals have a lung while others have gills, but no animal has both.[107]

(*Ch.* 11.) Now, seeing that every animal requires food to maintain its existence, and also needs refrigeration to preserve itself from perishing, nature makes one and the same organ minister to both these requirements. For just as in some animals she has made the tongue serve for the perception of flavours and also for the communication of ideas, so has she made the part known as the mouth serve, in animals that have a lung, both for the comminution of food and for inspiration and expiration.[108] But, in animals that are without a lung and do not breathe, the mouth serves for the comminution of food,[109] while there are gills to minister to refrigeration; supposing, that is, the animal to be one that needs [*special organs of*] refrigeration.[110]

As to the manner in which the organs that have been mentioned respectively produce refrigeration, this is a subject of which we shall speak hereafter. In order, however, to prevent the food from hindering the process, much the same plan is adopted in animals that breathe air as in animals that are cooled by the admission of water; for as the latter do not take in food at the same time as they take in water, so the former abstain from swallowing during inhalation. Should they act otherwise, they are choked by the food, fluid or solid as the case may

476, a, 30

be, slipping into the lung through the windpipe. For the windpipe lies in front of the œsophagus,[111] that is of the passage through which the food passes to the stomach.

Now in those sanguineous animals that are quadrupedous, and bring forth their young alive, the windpipe is provided with a kind of lid, namely the epiglottis. In birds and in oviparous quadrupeds there is no such provision, but the same result is brought about by the animal contracting the entrance of the windpipe.[112] For the Ovipara contract the windpipe during deglutition, while the Vivipara shut down the epiglottis. Then, when the food has passed, the windpipe is again expanded, or the epiglottis is again raised, and air is admitted for the purpose of refrigeration. As for animals that have gills, they first discharge the water through these appendages, and then take in food and transmit it through the mouth. For they have no windpipe, so that any mischief that could happen to them would not be the miscarriage of water into that passage, but its admission into the stomach. On this account both the discharge of the water and the deglutition of the food are performed by them with great rapidity; and, as there is no possibility of their chewing their food,[113] their teeth are sharp and their dentition[114] in almost all cases serrated.

(*Ch.* 12.) As regards those aquatic animals that are cetaceous,[115] that is to say the dolphins, the whales, and such other animals as have the so-called blowhole, any one might fairly feel puzzled, though a rational explanation can be given even as to these. For though they are apodous, and though they have
476, b, 16

a lung, nevertheless they take in sea-water. The explanation, however, which we give of this is that the water is not taken in for the purpose of refrigeration, for these animals have a lung and their refrigeration is effected by respiration. This, too, it is that explains why they keep their heads above the surface when they are sleeping, and snore; as is at any rate the case with the dolphins.[116] Moreover, when they chance to be caught in the fisherman's nets they soon perish, being suffocated by the stoppage of their respiration.[117] Again, they are to be seen on the surface of the water, coming there in order to breathe. Inasmuch, however, as they must necessarily take their food in the water, the water must of necessity get admission to their mouths, and must as necessarily be again discharged, and it is to meet this necessity that they are all provided with a blowhole. For it is through this passage that they discharge the water they have taken into their mouth, just as fishes discharge it through their gills.[118]

The position of the blowhole is a further indication of this. For it does not lead to any of the organs that are rich in blood, but is situated in front of the brain, and here it discharges the water.[119]

A similar explanation may be given of the fact that the Malacia (*cephalopoda*) and the Malacostraca (*crustacea*),[120] by which latter I mean such animals as those known as Carabi (*spiny lobsters*) and Carcini (*crabs*), also take in water. For none of these animals have any need of respiration, seeing that they are all bloodless and have but little heat, so that the water in which they are bathed is sufficient for their due

477, a, 1

refrigeration. They discharge the water, then, lest, being taken in at the same time as the food, it should flow into the stomach. In the Malacostraca (*crustacea*), such as the Carcini (*crabs*) and Carabi (*spiny lobsters*), the water is discharged through the overfolds alongside of the shaggy appendages;[121] and in the sepias and poulps through the pipe which is above the so-called head. But these are matters of which a more detailed account has already been given in the Historia Animalium.

The explanation, then, which we give of the taking in of water is that in some cases it is subservient to refrigeration, and that in others it occurs because animals that are by nature aquatic must needs take their food out of the water in which they live.

(*Ch.* 13.) We have next to treat of the means by which refrigeration is effected in animals that breathe, and in animals that have gills. Now, that all animals breathe that have a lung, has already been stated. But the reason why only some animals have this organ, and why such animals need respiration, is this. To the nobler kinds of animals a greater amount of heat has been allotted; for with greater heat is necessarily associated a nobler soul; and on this account animals are all of nobler nature than plants. Wherefore, also, those animals whose lung is most richly supplied with blood and heat are of more than average bulk;[122] and the animal that possesses the most abundant and the purest blood of all—namely, man—is of all the most upright, and alone of all has his upper part turned towards the upper part of the universe,[123] in virtue of his pos-

477, a, 23

sessing a lung with this kind and quantity of blood. It is this part, then, as much as [124] any other that can be named, that in man, and in such other animals as have it, must be held to constitute the essential character.

Such, then, is the final cause for which animals have a lung. But as to the material and the efficient cause, we must [125] suppose that the ultimate composition of some animals is such that they have this part, just as the ultimate composition of many others is such that they have it not. For some animals are mainly formed of earth—in this resembling plants—while others are formed of water, as are aquatic animals; while animals that fly and animals that live on land are formed in the one case of air, and in the other of fire; and they are so distributed that each is in a station of which the constitution is akin to its own.

(*Ch.* 14.) Empedocles, then, was in error when he said that the hottest animal and those that had most fire were such as live in water, and that they took refuge there in order that their excess of natural heat and their deficiency in cold and fluid might be balanced by the contrary characters of the medium, inasmuch as water was not so hot as air.[126] For in the first place it is utterly inconceivable how, after being severally generated on the earth, they should be able to change their habitat to the water; for they are almost all apodous. Yet Empedocles, speaking of their original formation, says that they are generated on the land, but migrate from this to the water.[127] In the second place, according to all appearances, they are not hotter than land animals;

477, b, 10

for some of them are utterly destitute of blood, and others have but little. But in deciding what kind of animals should be called hot and what kind cold, Empedocles made unsupported assumptions.[128] As regards, however, the cause of which Empedocles speaks, it is in a certain sense correct to say that organisms seek to attain the mean, but nevertheless what he says on the subject is assuredly not true.[129] For those animals that present excesses due to acquired habits of body find security in places and in seasons of character contrary to such excess. But an animal, so far as its natural or material constitution is concerned, is most secure in places of a constitution similar to its own. For the matter out of which any given animal is made is not the same thing as the conditions, persistent or temporary, of that matter.[130] I mean, for instance, that if nature were to make a thing of wax or of ice, she would not give it security if she set it in a hot medium; for it would speedily be destroyed by this contrary inasmuch as heat melts that which derives its consistency from cold. Neither, again, if a thing consisted of salt or of nitre, would nature place it in water; for things to which hot and solid matter give their consistency are dissolved by fluid. Supposing, then, that fluid and solid are the materials of which all bodies are made,[131] such as consist of fluids will reasonably have their place in fluids, and such as consist of solids will have their natural home in solids; and similarly with things that consist of cold matter. For this reason trees grow not in water but in earth; and yet, if what Empedocles says as to things with excess of heat

477, b, 29

were true, these trees should by parity of reasoning migrate to the water, because of their excess of solid matter. For thither they would go, not in virtue of its cold, but in virtue of its fluid constitution. The material composition then of a thing, that is, its natural composition, agrees with the composition of the place in which it exists; things of fluid composition are in water, things of solid composition are on land, and things of hot composition are in the air. Constitutions, however, that are derived from habit, if they have an excess of heat, are best off when placed in cold, and, if they have an excess of cold, when placed in a hot environment; for the environment equalises their excess and reduces it to the mean. Such reduction to the mean must be sought [*by migration*] within the medium of which the material constitution tallies with that of the organism, and in changes of season by which all media alike are affected. For it is possible for the habitual constitution to be contrary to that of the environment, but it is not possible for the material composition to be so.

Thus much, then, in contradiction to the statement of Empedocles, that some animals live in water because of the heat of their natural constitution, while others live on land because of their opposite composition; thus much, also, as to the reason why some animals have a lung, while others are without that organ.

(*Ch.* 15.) As to the reason why those animals that have a lung take in air and respire, and especially those among them whose lung is rich in blood, the explanation is to be found in the spongy character
478, a, 13

of this organ, which is full of pipes, and in the fact that of all the so-called viscera it is the lung which is most abundantly supplied with blood.

For those animals whose lung is rich in blood require that their refrigeration shall be effected with rapidity, seeing that it requires but very little to destroy the balance of their vital heat. They require, moreover, that the cooling agent shall make its way into every part of the lung, because of the abundance of its blood and heat. Both these requirements can be easily fulfilled by air. For air is of a subtle nature, so that it can permeate all parts, and this with speed, and therefore can produce rapid refrigeration; whereas water is of an opposite character. The reason why animals whose lung is rich in blood have more perfect respiration than other animals is also manifest; for, the greater the heat, the greater the demand for refrigeration.

The inspired air, at the same time as it permeates the whole lung, also passes with readiness to the source of heat, which is in the heart. (*Ch.* 16.) For the heart is connected with the lung by passages,[132] the disposition of which must be studied in dissections, and in the description given in the Natural History of Animals.

The natural constitution of animals, then, is such that they all, without exception, require refrigeration because of the cardiac fire in which their soul is incorporate. In animals that in addition to a heart have also a lung, this refrigeration is effected by breathing; but in such animals as fishes, which, though they have a heart, have no lung, it is effected by the passage of water through the gills,

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these animals being of aquatic nature. As regards the position of the heart in relation to the gills, the treatises on anatomy must be consulted for pictorial representation,[133] and the Natural History of Animals for detailed description.[134] It may be well, however, to give here a short account of the matter, and the arrangement in summary is as follows. The position of the heart in fishes would appear to the eye to be different from its position in land animals. In reality, however, it is the same in both cases. For the point of the heart is in both turned in the direction in which the animal inclines its head; but inasmuch as the head is not moved in the same direction in fishes as in land animals, the heart in the former has its apex turned towards the mouth.[135] From the extremity of the heart a tube, resembling a sinewy blood-vessel, runs to the central place, where all the gills unite with each other.[136] The tube here described is the largest, but there are also others on either side of the heart, and these run to the extremity of each gill, and it is through them that the cooling, due to the continuous passage of the water through the interstices of the gills, is imparted to the heart.

Corresponding to the motion of the gills in fishesis the motion of the thorax in animals that breathe; for this moves upwards and downwards in frequent alternation as the breath is taken in or expelled.

Animals that breathe in a limited amount of air that is unrenewed are suffocated;[137] [*and the same happens to fishes in a limited amount of water;*] for the air or the water soon becomes hot, being heated

by contact with the blood. But if the medium be hot, refrigeration is arrested.

Again, if the motion of the lung in animals that breathe, or of the gills in animals that live in the water, be prevented, be it by disease or by old age, death forthwith ensues.

(*Ch.* 17.) All animals alike, then, present these two phenomena: they are all born and they all die. The modes, however, of these occurrences present specific differences. For decay also is not without diversity, though its forms have a common element.

Death is either violent or natural; violent when the originating cause is something external; natural when the cause is internal, and when the death is due to the original constitution and not to some adventitious ailment.

Now, in plants this natural ending is termed withering, while in animals it is termed senile decay. Death and decay appertain to all living things alike that are not imperfect. To the imperfect also they appertain after a fashion, but not in exactly the same way. By imperfect I mean such things as eggs and the seeds of plants as yet without roots.

Now, in all living things decay is brought about by the failure of heat; and in perfect creatures by failure of heat in the part in which the essential principle resides; and this, as has been already stated, is placed at the meeting point of the upper and the lower parts; namely, in plants at the junction of root and stem;[138] in animals that have blood, in the heart; and in bloodless animals, in the part that is analogous to a heart.

In some of these bloodless animals, however, the

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centre of life is not one, but multiple; that is to say, there are many centres potentially, though not actually. And this is the reason why some insects live after their body has been divided; and why, even among sanguineous animals, such as are not too highly vitalised continue to live for a considerable time after their heart has been removed. Such, for instance, is the case with tortoises, who, so long as their shell is left, struggle with their feet after the removal of the heart,[139] because their physical constitution is of low grade and approximates to that of insects.

The principle or source of life is lost to its possessor when the heat with which it is associated is no longer tempered by refrigeration; for then, as has been repeatedly observed, it is consumed by its own activity.

When, therefore, the lungs or the gills, as the case may be, have in the course of time got dried up, and have become hard and earthy, their motion is impeded, and they can no longer be duly elevated and depressed; and at last something happening that intensifies this condition, the fire burns out from exhaustion. Thus too it is that in old age the occurrence of even slight ailments causes speedy death, for in old age the heat is but scanty—most of it having been exhaled in the course of a long life—and it is therefore soon extinguished should any kind of stress affect the heart; for its fire is now like a small and feeble flame which the slightest movement will put out.

On this account also the death that comes in old age is painless, for the aged die without any violent

affection befalling them, and the parting of their soul is quite unfelt.[140]

Again, all such diseases as cause the lung to become hard—be it by tubercles or by residual matters or by excess of morbid heat, as in fevers—increase the frequency of the respiration, because the lung cannot be raised up or depressed in sufficient degree; and finally, when its motion is entirely stopped the sick man gives out his last breath and dies.

(*Ch.* 18.) Birth,[141] then, consists in the first incorporation of the nutritive soul in its hot substratum, and life is the maintenance of this embodiment. Youth corresponds to the growth of the primary organ of refrigeration, old age to the wasting of this organ, while the interval between these two periods is the prime of life.

Death and decay when violent consist in the extinction or the exhaustion of the [*vital*] heat, either of which may cause dissolution. Natural death and natural decay consist in the exhaustion of this same heat, but only when such exhaustion is brought about by lapse of time and fulfilment of the natural term of life. The termination is in plants called withering, but in animals it is called death; and when such death comes in old age, it is due to the senile inability of the lung to produce refrigeration, and the consequent exhaustion of the heat.[142]

We have now explained in what birth, life, and death severally consist, and for what reasons animals are subject to them.

(*Ch.* 19.) It is plainly apparent also from what has been said why animals that breathe are suffocated when placed in water, while fishes are suffocated

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when placed in air; for in these latter refrigeration can only be brought about by water, while in the former it can only be brought about by air, and by the change of place each is deprived of its requirement.

We now proceed to explain what is the cause to which the motion, in some animals of the lung and in others of the gills, is due; and how by the elevation and depression of these parts, in the one case air, in the other case water, is taken in and discharged; and, lastly, we shall describe the structure of these organs.[143]

(*Ch.* 20.) In connection with the heart are three phenomena that might be taken to be of one and the same nature, but are not so in reality. These are palpitation, pulsation, and respiration.

Palpitation, then, is due to the driving inwards of hot matter from the rest of the body to the heart, in consequence of a refrigeration caused either by residual substances or by substances derived from body-waste.[144] Such palpitation occurs in sundry diseases, and especially in that known as Palmus. It occurs also in terror, for in terror, no less than in the above-mentioned disease, the upper parts of the body are chilled, and the hot matter, escaping thence and becoming concentrated in the heart, causes this organ to palpitate.[145]

Sometimes indeed the concentration is carried to such an extent as to extinguish life, and the animal dies from terror and the morbid affection which terror produces.[146]

The pulsation of the heart, that is the motion which we see always going on without intermission

479, b, 27

in that organ, resembles the throbbing in an abscess; only the latter motion, which continues until the pus is fully concocted, is accompanied by pain, inasmuch as the change going on in the blood is an unnatural change. This affection is comparable to ebullition; for ebullition occurs when fluid is aerified by heat, for its bulk then becomes greater, and in consequence it rises up. But while in the process of ebullition the fluid finally escapes beyond the limits of the vessel that contains it, the termination in the abscess is that the fluid, if it be not dispersed by evaporation, becomes thickened, and corrupt matter is formed.

Now the heart is constantly being supplied with fluid[147] derived from the food; and this, expanding under the influence of heat, lifts up the outer tunic of the heart and so causes pulsation. And this goes on continuously; for the fluid matter, out of which the blood is formed, is always flowing without interruption into the heart; this being the place where the blood is first elaborated, as is plainly shown in the development of the embryo. For the heart is visible and is seen to contain blood,[148] at a period when the vessels are not yet distinctly formed.

The uprising of the vapour [*of food into the heart*] is more abundant in the young than in those of more advanced years, and consequently pulsation is greater in youth than in old age.[149] Again, all the vessels pulsate, and pulsate simultaneously, inasmuch as they are all in connection with the heart; and, as the heart is always in motion, so also are they, simultaneously with it and with each other.[150]

Palpitation, then, is the reaction from the forcible
480, a, 13

compression of hot matter in the heart by cold. Pulsation is the aerification of the fluid matter as it gets heated; (*Ch.* 21) and respiration is the result of the increase of the hot matter in which the nutritive principle is embodied. For just as all the other constituents of the body require sustenance, so also does this hot matter, and more than they, for it is the cause of their being nourished.

Now when the hot matter is increased, it cannot but cause the organ which surrounds it to expand. This organ we must picture to ourselves as being constructed much after the fashion of the bellows in a smithy; for this represents fairly enough the form that has been given to the lung, as also to the heart.[151] We must further picture the bellows as being double;[152] for it behoves the nutritive principle to be in the centre of the cooling influence.[153]

The organ, then, increases in bulk and expands; and, when it expands, so also of necessity must the part that environs it. Indeed, this expansion is visible during inspiration; for when persons inspire, they expand their chest; because the principle which is lodged within, [*that is, the internal fire*], causes a similar expansion in the part we have compared to a pair of bellows.[154] But, when the organ expands, the outer air will of necessity flow in, just as it flows into the expanded bellows, and being cold, and productive of refrigeration, will quench the excess of the internal fire. And as the part expanded with the increase of the heat, so also will it of necessity subside with its diminution; and by this subsidence the air which was previously admitted will be again di charged; and, though it was cold when admitted,

480, b, 4

when discharged it will be hot, having been heated by contact with the hot matter within the part, and especially so when the animal is one whose lung is rich in blood.

For the air makes its way into numerous pipes or narrow passages within the lung, and alongside each of these run blood-vessels, so that the lung seems completely full of blood.

The entrance of the air is termed inspiration, and its exit is called expiration ; and so long as the animal lives, these motions of inspiration and expiration go on without interruption, so that life and respiration are inseparably bound together.

After a like fashion also is the motion of the gills produced in fishes. For when the hot matter in the blood expands as it flows through the parts, it lifts up the gills and lets the water pass through,[155] but when the hot matter has been cooled and passes down to the heart through the channels,[156] the gills fall back again and discharge the water. And this expansion of the hot matter in the heart, and this return of it thither when cooled, go on in continuous alternation. Life or not-life depend, then, in these animals on the admission of the water, as in animals that breathe they depend on the admission of air.

We have now treated of Life and Death, and have also pretty fairly discussed such other topics as are akin to them. Health and disease are subjects that come within the province not merely of the physician, but so far as the consideration of their causes goes, within that of the natural philosopher.

That these inquirers differ from each other, and examine the subject from distinct points of view,
480, b, 24

must be fully recognised. Yet that their respective provinces are to some extent conterminous is shown by the fact that such physicians as are men of refinement and wide culture[157] are wont to talk of the laws of nature, and profess to derive thence their principles of practice, while the most accomplished of the natural philosophers rarely fail in the end to touch on the principles of medicine.

480, b, 30

NOTES

1. Aristotle says 'in some animals,' because respiration is limited by him to animals that breathe air by lungs. Cf. Note 43.

2. 414, a, 20. *De Animâ* ii. 2, 16.

3. That the several faculties or parts of the soul of an animal, with the doubtful exception of the intellectual faculty, are inseparable from each other is laid down very positively in the *De Animâ* (413, b. ii. 2, and 411, b. i. 5, 30). The main fact on which this conclusion is based appears to be that, when such an animal as an insect is divided, it is not found that one piece retains the nutritive, another the sensory, and another the motor faculty, but that any part that retains one of these faculties also retains the rest. Cf. Note 17.

4. A very unsatisfactory definition of 'anterior,' even if vision be taken to represent the senses, as it is elsewhere (712, b, 15–20). *De Incessu* 14, 7.

5. Because, as appears later (cf. Note 31), this is the most advantageous position, inasmuch as by it the nutritive principle is in the centre of the parts to be nourished, and nature cannot but select the most advantageous plan. Cf. Introd. p. 2.

6. Upper in the universe is defined elsewhere (208, b, 19. *Nat. Aux.* iv. 1, 5) as the direction in which fire and light bodies ascend; lower as the direction in which heavy bodies fall.

7. 'Nor is that an absurd similitude or conformity which has been remarked between man and a plant inverted. For the root of the nerves and faculties in animals is in the head, while the seminal parts are the lowest—the extremities of the legs and arms not reckoned. In a plant, on the other hand, the root (which answers to the head) is regularly placed in the lowest part, and the seeds in the highest.' —Bacon, *Nov. Org.* II. xxvii.

8. Aristotle supposed that the food of plants was taken in exclusively by the roots; and that previously to absorption it had undergone elaboration by the agency of the heat of the soil, which served the plant in lieu of a stomach. A consequence of this was that plants had no excretions (*De Part.* ii. 3. 10, ii. 10. 2; 650, a, 22, and 655, b, 32), for their food contained no useless residue, and any

excess in amount was used up in fruit and seeds. A necessary corollary of this was that the absorbed matter was very composite, containing as it must all the constituents of the plant, even to the savours of the fruits (*De Sensu* 4. 7 ; 441, a, 30), already formed.

These views were universally accepted for many centuries. Van Helmont (1577–1644), however, who, like Thales (983, b, 20. *Metaph.* i. 3, 5), held that the ultimate constituent of all things was water, supposed that this fluid was the only thing absorbed by the roots, and that it was converted by the activity of the plant into all the various constituents of its substance. Later on Malpighi, in his *Anatomes Plantarum Idea* (1671), showed that it was in the leaves that the crude materials absorbed by the plant were converted into the substances required for its growth ; after which Hales (1677–1761) proved that the leaves were not merely laboratories for the formation of nutritive substances, as Malpighi had supposed, but also the channels through which most of the materials required by the plant made their entrance, a much larger part of its solid substance being derived from the air than from the soil or the water. If to these successive discoveries be added one which Sachs (*Hist. Bot.* p. 464) ascribes to Jung (1587–1657), that plants do give off excreta, it will be seen that the whole of Aristotle's doctrine as to the nutrition of plants has been swept away.

9. The text is undoubtedly corrupt. I have attempted, however, to give a meaning to δι' αὐτῶν, by supposing Aristotle to allude to grafts and parasitic plants, which only derive food indirectly from the soil.

10. Cf. Introd. pp. 1–3. Aristotle's language as to the retention of vitality by the segments of a divided animal is not always quite consistent. Sometimes, as here, he speaks as though that segment alone remains alive which is in connection with the central part in which is lodged the heart or its analogue. Thus, in the *Hist. Anim.* (iv. 7, 3 ; 531, b, 30) we read 'All insects retain life when cut in two, except those that are either of excessively cold constitution or so small as rapidly to lose their heat. For even wasps live after such section ; and that segment, whether head or abdomen, that remains in connection with the central part retains life, while the head, if not so connected, dies.' But in other passages he speaks as though such connection with the centre were not absolutely necessary. Thus, speaking in the *De Animâ* (i. 5, 30 ; 411, b, 19) of insects that have been cut in two, he says 'Each of the two segments retains sensation and the power of locomotion for some time. That they do not retain these faculties permanently is not to be wondered at, for they have not got the organs that are required for their preservation. Nevertheless, all the several parts of the soul are present in each severed part, and [*these segmentary souls*] are similar in kind to one another and to the soul of the entire insect.' See also 413, b, 21. *De Animâ* ii. 2, 9, and 467, a, 19. *De Long. et Brev. Vitæ* 6, 4.

The contradiction is, however, more apparent than real. He holds that in insects the soul with its faculties exists dispersedly in all parts of the body, but that, even in insects, its main seat is in the heart or analogous organ. The difference, therefore, between the segment in connection with the heart and the segment not so connected is rather of degree than of kind.

11. It does not appear to what animals Aristotle here alludes. Among them, however, was probably the tortoise (cf. Note 139); perhaps also earthworms and eels.

Aristotle knew (508, b, 7. *Hist. An.* ii. 17, 24) that, when the tail of a lizard has been lost or removed, another grows in its place; but he did not carry his observations on divided animals far enough to discover that in some cases the separate portions develop into perfect animals; indeed, he expressly states (467, a, 21. *De Long. et Br. Vit.* 6, 4) that such is not the case. This was, in fact, not known till the middle of the eighteenth century, when it was shown by Trembley (*Mém. pour serv. à l'hist. d'un genre de Polypes d'eau douce.* Leyden, 1744) to be the case with the freshwater hydra; and then by Réaumur and others with earthworms, 'sea-millipedes,' starfishes &c. (*Mém. p. serv. à l'Hist. Nat. des Insectes*, vi. lxi. lxiv. lxix.).

12. The iteration and confusion, noticed in the Preface, is very conspicuous in this part of the treatise, and has necessitated some readjustment and dovetailing of clauses and sentences.

13. Cf. Introd. pp. 2–7. 411, b, 23. *De Animâ* i. 5. 30, and 467, a, 21. *De Long. et Brev. Vitæ* 6, 4.

14. There is no such discussion in the extant works. Perhaps it was in the lost treatise on plants.

15. Cf. Introd. p. 2. One is tempted to credit Aristotle with a knowledge of such organisms as the Polyzoa, or the social and compound Ascidia; but had he known of them, he would most assuredly have made mention of them here.

16. For ἐν τοῖς ἔχουσι, which is unintelligible, I read ἐν τοῖς ἐντόμοις.

17. 'Chez les animaux les plus inférieurs . . . . la faculté de sentir ne semble être l'apanage d'aucun instrument physiologique spécial, car elle peut persister dans tout fragment de l'être séparé du reste du corps.'—M. Edwards, *Leçons* xi. 356.

18. For αἴσθησιν I read κίνησιν.

19. Insects, such as grasshoppers, from which the viscera have been entirely removed and replaced by cotton-wool, as entomological specimens, if not pinned down, often fly away. As to the tortoise, see Note 139.

20. The seeds which Aristotle examined, and which led him to the erroneous belief that all seeds are bivalved, were beans and the like (752, a, 22. *De Gen.* iii. 2, 3). Theophrastus, though he tries to make out that the grains of corn are in some kind of a way bipartite or

bivalved, says this is much more conspicuous in the case of legumina (*Hist. Plant.* viii. 2, 2). The division of plants into those with a two-leaved and those with a one-leaved or leafless embryo, or, in modern terms, into dicotyledons, monocotyledons, and acotyledons, was first made in the seventeenth century by Ray.

21. The very doubtful word ἔχεται must correspond to the συνῆπται in the parallel passage in the *De Generatione* (iii. 2, 3; 752, a, 21), and refer to the junction of the two cotyledons, or *collar*, while ᾗ προσπέφυκε refers to the junction of the seed with the funicle, or *hilum*. These in the bean and most seeds are closely contiguous, and are considered by Aristotle to be identical. He regards this point as central, not only because it lies between the seed and the mother-plant, but because it is between the cotyledons on either side, and the plumule and radicle above and below.

22. This point of union between root and stem played an important part in the speculations of botanists even so late as in our own century. It was known by them as the *cor*, the *cerebrum*, the *fundus plantæ*, and later as the *collum*. Here Cesalpino, writing in the sixteenth century, located the soul of the plant; and though the Linnæan botanists of the nineteenth century neither knew what Cesalpino had done nor believed in a soul of plants, 'they still entertained,' says Sachs (*Hist. Bot.* i. ch. 2), 'a superstitious respect for this part of the plant, which is really no part at all; and this, it would seem, explains the fact that an importance, scarcely intelligible without reference to history, was once attributed to it, especially by some French botanists.'

23. Omit εἰς.

24. Cf. 665, a, 33. *De Part.* iii. 4, 2: 'In sanguineous animals the heart and the liver are visible enough when the body is only just formed, and while it is extremely small. For these parts are to be seen in the egg sometimes as early as the third day, being then no bigger than a point, and are visible also in aborted embryos while still excessively minute.' And again, 561, a, 11. *Hist. An.* vi. 3, 2, where it is said that the heart at its first appearance looks like a bloody spot, and palpitates as though endowed with life, a description which is the origin of the *punctum saliens* of later writers. The heart is not actually the first structure that appears in the embryo, but it is the first part to enter actively into its functions, contracting in the chick early in the second day of incubation, and becoming a few hours later rhythmical in its motion. Cf. Introd. p. 4.

25. 665, b, 15. *De Part.* iii. 4, 6.

26. Meaning of course mastication. 'The mouth, however, does not actually concoct the food, but merely facilitates concoction; for the subdivision of the food into small bits facilitates the action of heat upon it' (650, a, 10. *De Part.* ii. 3, 8).

27. Aristotle held that the objects of sense could act on the sense organs only through a medium to which they imparted their motion,

which it in turn communicated to the organ, whence it was conveyed inwards to the *sensorium commune*. Air and water formed the medium for sight, hearing, and smell alike, but not in virtue of the same quality. In sight it was the transparent (διαφανές) which was effectual; in smell it was a nameless something which, like the transparent, was common to both elements; and, similarly, there was another nameless something in them which served as the medium of sound. In short, as modern physicists assume the existence of a luminiferous ether, so Aristotle assumed the existence of three similarly hypothetical media, one of which he called the transparent, while the two others received in later days the names of the 'transolent' (δίοσμον), and the 'transsonant' (διηχές). See Torstrik, Notes to *De Animâ* ii. 7. The organs of these three senses were of course the eye, ear, and nose. These were connected with the interior of the skull and surface of the brain by certain passages or channels (πόροι), and this again was connected with the heart by blood-vessels; and, therefore, so far as anatomy went, either brain or heart might be the *sensorium commune* of these three senses. But it was not so, he thought, with touch and taste. Of these the flesh and the tongue could not be the actual sense-organs, for the analogy of the other senses showed that a sense-object could not produce the appropriate sensation if placed in direct contact with the sense-organ, but required the intervention of a medium, whereas an object gave rise to the sensation of taste or touch when placed directly in contact with tongue or flesh.

'If a coloured body be placed in direct contact with the eye, the eye will not see it. There must be a transparent medium, such as air, which is set in motion by the colour, and which in turn sets in motion the sense-organ, with which it is in continuity. For Democritus was mistaken in supposing that, if the interval between the eye and the object were a vacuum, vision would be so distinct that we should be able to discern so small an object as an ant, though it were at the distance of the heaven. . . . In reality, with a vacuum in place of a medium, there would be no vision at all. The same is true in the case of hearing and of smelling. A smell or sound sets the medium in motion, and this in turn moves the organ of sense. But when the object from which the sound or smell proceeds is placed directly upon the sense-organ, it produces no sensation. The same is true of touch, though it is not so evident, for reasons to be given hereafter' (419, a. *De An.* ii. 7), and again, 'The direct contact of an object with an organ of sense in no case produces a sensation. Thus, if a white body be placed in contact with the eye, there is no sensation of whiteness. This shows plainly that the sense-organ of touch lies deeper than the flesh. For the same must occur in the organ of touch as in the organs of the other senses. That is to say, it must be—as they are—insensible to objects in direct contact with it. The fact, then, that objects are felt when in contact with the flesh shows that the flesh must be the medium

that separates the object from the sense-organ ; the flesh and tongue standing to touch and taste apparently in the same relation as do air and water to sight and hearing' (423, b. *De An.* ii. 11).

The flesh, then, and the tongue must be the medium and not the organs of these senses. But the flesh and the tongue were in no connection whatsoever with the brain (nerves of course being then undiscovered), and were indeed shut off from it completely by the bony walls of the skull. They were, however, not thus shut off from the heart, which was, moreover, made of the same substance as themselves, and could therefore readily respond to their motion. As, then, all five senses alike could communicate their motions to the heart, while only three could communicate them to the brain, the heart and not the brain must be the *sensorium commune.*

The flesh, then, being the medium of touch and taste, what were their sense-organs? There were none distinct from the sensorium, none being required, inasmuch as this medium was itself in direct contact or contiguity with the *sensorium commune*, and consequently a motion which affected the medium affected the sensorium simultaneously, so that the heart was at once sensorium and sense-organ. The flesh stood to the heart in the relation that a shield stands to a man's body with which it is in contact. 'When the man is wounded by a blow through the shield, we are not to suppose that the shield is first struck and then strikes the man, but shield and man are smitten together ;' and similarly the motion of the tangible object is communicated to flesh and heart, that is to medium and sensorium simultaneously (423, b, 15. *De An.* ii. 11, 13).

28. Aristotle had previously argued that, as the sensory principle was clearly located in the heart, there also must be located the principle of nutrition. Here he reverses the argument.

29. E.g. Plato in the *Timæus* (Jowett's Transl. ii. 568), who probably borrowed the opinion, as Galen says (*De Usu Part.* i. 8) he did his physiology generally, from Hippocrates. Democritus, also (Zeller, *Pre-Soc. Ph.* ii. 258), had taught that the sovereign part of the soul was in the head, and Diogenes of Apollonia, more directly, had held that the brain was the seat of sensation, being surrounded by a layer of hot dry air, which was in connection with the sense-organs by means of the blood-vessels, and so sympathised with their motions and affections (Grote's *Plato*, i. 65).

30. 656, b, 5. *De Part.* ii. 10, 10. See note 9 to that chapter in my translation, for a discussion of the reasons which led Aristotle to make the heart rather than the brain the seat of sensation.

31. As I understand this somewhat obscure passage, Aristotle divides the body into two departments : one, the heart in which the food is finally elaborated, and, the other, that part to which the food, thus elaborated, is distributed, that is to say, all the body excepting the heart. That the soul shall be placed in the former will be the most

advantageous arrangement for both; for the soul will thus be in a central position, and so best placed for the government of the whole; while no part of the body will be far removed from the source of its sustenance and heat. By τὸ δεκτικόν, then, is meant not the stomach, which is the receptacle of the *undigested* food, but the mass of the body, other than the heart, which is the recipient of the *elaborated* food.

32. I omit the words τοῦ τοιούτου as unintelligible; and, a line or two on, I read τόπον for τρόπον.

33. This seems at first inconsistent with the former statement that the final elaboration of the food takes place in the heart. Aristotle, however, did not suppose that *all* the material that passed to the heart was there elaborated; for he speaks (651, a, 18. *De Part.* ii. 4, 8) of the serum as 'the watery part of the blood that has not *as yet* undergone concoction'; moreover, the elaborated blood was held by him to undergo a second elaboration in the several organs, so as to adapt it to special uses; thus the blood by a local concoction was converted in the mammary organs into milk (776, b, 35. *De Gen.* iv. 8, 13); in the generative organs into the seminal fluid (719, b, 2. *De Gen.* i. 12, 2); and in all parts of the body into fat (652, a, 9. *De Part.* ii. 6, 6).

Natural heat, and all the vital activities that depend on that heat—nutritive, sensory, and motor—were in some degree diffused throughout the body, though their central seat and fountainhead was in the heart.

34. Aristotle's views as to the nature of fire are very obscure, and his language far from consistent. Sometimes (*e.g.* 761, b, 18. *De Gen.* iii. 11, 10; and 649, a, 20. *De Part.* ii. 2, 13) he speaks of it as having no independent existence, but as requiring some other material substratum; apparently inclining to the view more distinctly enuntiated by his pupil Theophrastus (*De Igne* 3), that fire is not an actual material substance but an affection of matter.

More usually, however, he regards fire as an actual material substance, being one of the four compounds that result from binary combinations of the four primary forms of ultimate matter or protyle (ἡ πρώτη ὕλη), viz. hot, cold, solid, and fluid (see my translation of the *De Partibus* ii. 1, notes 3 and 4). Of these, solid and cold form earth, fluid and hot form air, cold and fluid form water, while hot and solid constitute fire; the first-mentioned constituent in each pair predominating (331, a, 4. *De Gen. et Corr.* ii. 3, 8).

Anything that neutralises or removes either of the two components in any one of the pairs of course destroys the compound.

Thus cold and fluid neutralise respectively hot and solid, which are the components of fire, and the termination of fire which is produced by these contraries is called by Aristotle σβέσις or extinction.

But, independently of this violent termination—violent because due to external agency—fire can come to an end of itself, by what Aristotle

terms μάρανσις or exhaustion; and it is as regards this exhaustion that Aristotle's precise views are doubtful. That the exhaustion is due to want of fuel is manifest; but how comes it about that fire requires fuel for its maintenance? Aristotle's explanation apparently must have been much as follows:—There is a tendency in fire for its two constituents, hot and solid, to separate from each other; and the solid matter, combining with the air, passes off as smoke, which is a compound of air and solid matter or earth, in which solid matter is the predominating constituent (331, b, 26. *De Gen. et Corr.* ii. 4, 11; 443, a, 27. *De Sensu* 5, 7). Consequently fire would come to an end if left to itself, and no fresh solid matter or earth were supplied. But this is done by means of fuel, which furnishes solid matter to take the place of that which is lost as smoke. Thus the fire is always being destroyed and always being reconstituted, 'like a river,' says Aristotle, 'ever flowing away and ever being formed anew.'

This is, I think, the only coherent account that can be given of Aristotle's views as to fuel; but it must be acknowledged that there are passages difficult to bring into exact accord with it. His notions were probably not perfectly fixed and definite, though they involved a rudimentary conception of the process of combustion.

In the living body, the fire in the heart may, like fire outside, be extinguished by cold; and animals die when exposed to this in excess, partly from the direct action of the cold, which neutralises the heat, and partly because cold checks the action of the stomach, and so cuts off the supply of fuel. For the fire is fed by fuel derived from the food, which rises up in the form of vapour to the heart (456, b, 4. *De Somno* 3, 3). If this fuel fails, as in starvation, the animal dies from exhaustion of heat (466, b, 28. *De Long. et Br. Vitæ* 5, 10). But the same result will of course ensue if the fire consumes the fuel faster than the stomach can replace it; and this will be the case if the fire be excessive. To prevent this, the fire must be kept in bounds; and this is effected by respiration of air, or, in fishes, by the passage of water through the gills. See Introd. p. 45.

35. Vital heat, according to Aristotle, suffers in two opposite ways in old age. Firstly, much of it has been lost in the course of years, so that the feeble remnant can be easily extinguished; secondly, the lungs have become hardened, by gradual loss of fluid, and perform their duty of tempering the cardiac heat inadequately, so that the heat burns up its fuel too quickly, and is thereby exhausted. It is to this second factor that the text refers (see Note 97).

Stripped of erroneous detail, there is this solid nucleus of truth in Aristotle's account of senility: the temperature of the body is lower in old age than in youth, and its regulation is less perfect. Cf. Introd. p. 13.

36. See Introd. p. 27.

37. The πνιγεύς was clearly some kind of receptacle inside which

fuel could be burnt, and was provided with a cover by which all access of air could be prevented; and from a passage in Aristophanes (*Clouds* 96) it would appear that this cover was probably dome-shaped. It can scarcely, then, have been an oven, but must rather have resembled a warming-pan. I have rendered it 'chafing-pan,' as a general term which would include this implement and any other of analogous construction.

38. It seems clear that for θερμότητος should be read ψυχρότητος. The porosity of the ashes allows the excessive heat to escape, and a moderate cold to enter, though it obstructs the ingress of excessive cold.

39. No passage answering to this reference can be found in the *Problems* as they have come down to us. It is strange that Aristotle should not have noticed a most palpable and fatal objection to his explanation of how it comes about that fire goes out when closely and continuously covered up, so as to be kept from access of air. It is obvious that, if such going-out were due to the fire being no longer kept in bounds, and therefore rapidly consuming its fuel, this fuel should be found to be exhausted when the cover is finally raised, whereas such is of course not the case.

40. If ζῷον be the true reading, it must here be used to include plants, and cover all things with life. But perhaps for πᾶν ζῷον should be read πάντα τὰ ζῶντα.

41. Aristotle entertained the strange notion that a fan cools a heated body not merely by bringing a continuous current of colder air into contact with it, but directly by its own motion, that is, independently of the air. 'Every hot body,' he says (667, a, 27. *De Part.* iii. 4, 30), 'is cooled by the motions of bodies external to itself.' And, again, he supposes (669, a, 36. *De Part.* iii. 6, 8) that when an animal is under water its lung will continue in motion, and that, though no air is admitted, the motion itself will produce a certain amount of refrigeration in the neighbouring parts. Insects again are, he says (475, a, 14. *De Resp.* 9, 4), cooled sufficiently by the mere motion of their abdomen.

Of all his erroneous notions this, and the idea that right was in nature superior to left and upper to lower, appear to me to have been the most mischievous.

42. The 'certain kinds of stones' must have been such as are bad conductors of heat. 'Une plante donnée,' says De Candolle, 'résiste mieux aux extrêmes de la température dans un terrain plus compacte ou moins bon conducteur du calorique ou moins doué de la faculté rayonnante, que dans un sol ou trop léger ou bon conducteur, ou rayonnant fortement le calorique.'

43. Aristotle confines the term 'respiration' to the admission and discharge of air to and from lungs; whereas we often use it, in a wider sense, to include all processes by which oxygen is absorbed and carbonic acid discharged.

44. In amphibia and in some lizards the lungs are reduced to simple membranous bags; and, though these bags are in most reptiles more or less divided out by internal dissepiments, which increase the respiratory surface, the parenchyma is always of a much looser and more coarsely spongoid character than is the case in mammals. There is very much difference in different groups in the extent to which the subdivision of the lung cavity is carried; and it is noticeable, as showing what care Aristotle took in his anatomical investigation of these organs, that he rightly states (671, a, 16. *De Part.* iii. 8, 4) that the lungs of sea-tortoises are in this respect superior to those of land-tortoises (cf. Cuvier, *Leçons* iv. 324 and 332).

The lungs in birds are very much smaller in proportion to the bulk of the body than in mammals; but are far more subdivided and much more amply supplied with blood than those of reptiles or amphibia. In annotating the *De Partibus* (iii. 6. Note 10) I suggested that Aristotle, when he speaks of the lungs of birds as resembling those of reptiles in their spongoid character, might have taken the air-sacs of the former for the lungs; but on further consideration I think this an improbable supposition, and that it is very unlikely that Aristotle anticipated Harvey in the discovery of these air-sacs. Nor is such a supposition required; for, owing to the walls of the deeper air-tubes being thick and remaining always patulous, and those of the superficial tubes into which they open being transparent, the lung of a bird presents on section a peculiar perforated tubular appearance (Carus, *Comp. Anat.* p. 118); and this, with their small size, would be to Aristotle a sufficient justification for regarding them as of inferior character.

45. It appears from the *Hist. Anim.* (v. 33, 3), as also from a passage later on in the treatise (cf. Note 100), that the Emys was a freshwater tortoise, probably the *E. Europæa.* But in the *De Part.* (iii. 9, 2; 671, a, 32) Emys is said to have a soft shell, which is not the case with any freshwater tortoise with which Aristotle was likely to have been acquainted, though it is true of the Trionyx of the Nile. Aristotle's soft-shelled tortoise can hardly have been anything but the *Testudo coriacea*, frequent in the Mediterranean; and the name Emys must have been common to this marine animal and to the freshwater tortoise. The words 'tortoises and Emydes' may therefore be considered as equivalent to 'land and water tortoises.'

46. Darwin (*Voyage of 'Beagle,'* p. 464), speaking of the Galapagos tortoises, says 'A seaman on board sank one with a heavy weight attached to it, thinking thus to kill it directly; but when, an hour afterwards, he drew up the line it was quite active.' Frogs will live for months under water, if this be constantly renewed, their cutaneous respiration sufficing for the maintenance of life; and they do not die for some hours, even when submerged in water from which all air has been removed. Cf. W. F. Edwards, *De l'Infl. d. Agens phys. sur la Vie*, pp. 48, 50.

47. Cf. Note 41.

48. Cf. Note 43.

49. See Introduction, pp. 17–19. There does not seem much difference between the accounts given by Anaxagoras and Diogenes. But the latter supposes a vacuum to be formed in the fish's mouth, which Anaxagoras holds to be impossible. Aristotle does not tell us what were their notions as to oysters.

50. Aristotle does not say why inspiration and expiration must be by one and the same channel. Apparently, he is merely guided by the analogy of the wind-pipe.

51. Cf. Introd. p. 19.

52. Cf. Introd. pp. 20, 21.

53. Cf. Introd. pp. 28, 29.

54. Cf. Introd. pp. 25, 26.

55. One cannot see what led Aristotle to say that men hold their breath when the air is cold. Perhaps he meant no more than that they often, when going suddenly into frosty air, close the mouth and breathe solely by the nostrils. Or perhaps he meant to say—and this is what we should have expected him to say—that respiration is slower in a cold than in a hot medium. But this—though it is true of cold-blooded animals, and of such mammals as hybernate—is not true of man and such warm-blooded animals as do not hybernate, unless the difference of temperature be very great. 'Cette accélération,' says W. Edwards, 'n'a ordinairement lieu d'une manière bien sensible, que lorsque la chaleur est accablante ou qu'elle est très incommode' (*De l'Infl. d. Agens phys. sur la Vie*, Paris, 1824, pp. 296, 301, &c.)

56. The passage in the *Timæus* is as follows: 'Let us once more consider the phenomena of respiration, and enquire into the causes which have made it what it is. They are as follows:—Seeing that there is no such thing as a vacuum into which any of those things which are moved can enter, and the breath is carried from us into the external air, the next point is, as will be clear to every one, that it does not go into a vacant space, but pushes its neighbour out of its place, and that which is thrust out in turn drives out its neighbour; and in this way everything at last comes round to that place from whence the breath came forth, and enters in there, and, following the breath, fills up the vacant space; and this goes on like the rotation of a wheel, because there can be no such thing as a vacuum. Wherefore, also, the breast and the lungs, when they emit the breath, are replenished by the air which surrounds the body, and which enters in through the pores of the flesh and is driven round in a circle; and again, the air which is sent away and passes out through the body forces the breath inwards through the passage of the mouth and nostrils' (*Timæus*, Jowett's Transl. iii. 501).

57. This seems to imply that Plato thought the ultimate use of respiration to be the preservation of heat. And such may have been

the case, for Plato borrowed his main physiological doctrines from Hippocrates (Galen, *De Usu Part.* i. 8), who held (Galen, *De Util. Resp.* ch. 1) that the purpose of respiration was 'nutritio et refrigeratio,' by which apparently was meant that it supplied the internal fire with fuel and at the same time prevented it by refrigeration from consuming its fuel too rapidly. Cf. Note 59.

58. This passage seems to be a criticism of Democritus rather than of Plato. It is simply a repetition of what was said by Aristotle when criticising the former (pp. 77, 78). Very probably the passage was interpolated, and in the wrong place, by the transcriber, when he was collating two versions of the treatise.

59. It may have been Hippocrates who thus taught (cf. Note 57), though I can find no passage to this effect in his admittedly genuine treatises. But in the spurious treatise *De Flatibus* (ch. v.) we read 'Air is the nutriment of fire; for fire, if deprived of air, cannot subsist;' and again in the *De Alimento* (ch. xi.) 'For air is a nutriment.'

Sir T. Browne (*Vulg. Errors*, iii. 21) says of air, 'Although in some manner it concurreth unto nutrition, yet cannot it receive the proper name of nutriment, and therefore by Hippocrates *de alimento* it is termed *Alimentum non Alimentum*, a nourishment and no nourishment. That is in a large acception, but not in propriety of language; conserving the body, not nourishing the same; not repairing it by assimilation, but preserving it by ventilation; for thereby the natural flame is preserved from extinction, and so the individual supported in some way like nutrition.'

60. Not to all analogy; for there are animals, such as the Cœlenterata and certain Echinodermata, in which the mouth is the only outward opening of the digestive tract, and serves therefore also as anus.

61. 'So the nostrils are useful both for respiration and smelling, but the principal use is smelling; for many have nostrils which have no lungs, as fishes, but none have lungs or respiration, which have not some show, or some analogy of nostrils.'—Browne, *Vulg. Err.* iii. 21. Cf. 444, a, 25. *De Sensu* 5, 19.

62. That fishes, insects (444, b, 7–15. *De Sensu* 5, 22), testacea (443, a, 4. *De Sensu* 5, 2), cephalopoda and crustacea (534, b, 16. *Hist. An.* iv. 8, 25), and generally all animals that are not of imperfect or stunted development (425, a, 10. *De An.* iii. 1, 5), have the sense of smell, was inferred by Aristotle from their being attracted to suitable food from a distance, though he admits that the exact position of the organ of smell in these animals is uncertain.

The association, however, in man and the higher animals of this sense with the organ of respiration—or, as Aristotle would say, of refrigeration—led him to suspect a similar association in other cases; and consequently he located smell in the gills of fishes, in the blowhole of cetacea, in the drums of cicadæ, and, in other insects, in those thinner

parts of the integument which he supposed to serve for the regulation of heat (659, b, 15. *De Part.* ii. 16. Note 10, in my translation of that treatise).

There is not much greater certainty, even at the present day, as to the olfactory organs in some of these animals. It is very doubtful whether cetacea, fishes, or aquatic molluscs and crustacea can smell at all; and, though the existence of this sense in the terrestrial gasteropods and insects seems indisputable, there is an astounding diversity of opinion as to the position of its organ. Thus Cuvier thought that in the pulmonate gasteropods the whole integument served as olfactory organ; Treviranus placed it in the mouth; Carus in the orifice of the pulmonary sac; Leydig in the anterior part of the foot; while Moquin Tandon and others assign it to the upper tentacles. There is a similar variety of opinion in the case of insects; though most naturalists now agree in considering the antennæ as the chief, if not the only, olfactory organs in these animals. Cf. Jourdain, *Les Sens chez les Animaux Inférieurs*, ch. v.

63. That there should be an inherent tendency in the blood to move to and fro would not seem so strange a notion to the ancients as to us. For, as they were ignorant of the cause of tides, the sea would appear to have such a natural tendency.

64. Though the general meaning of the passage here quoted from Empedocles is clear enough, there are many words and phrases in it, of which the rendering can at best be conjectured. Much latitude must therefore be allowed to the translator.

65. It is plain from the context and from Aristotle's paraphrase that by λίφαιμοι Empedocles does not mean absolutely bloodless but partially so. The term σύριγγες is used by Aristotle for the air-passages; very probably Empedocles did not distinguish these from the blood-vessels, thinking that both contained a mixture of blood and air.

66. It is clear that Aristotle understood by ῥινῶν the nostrils, and a similar view is taken by Scaliger, by Sturz, and by Mullach (*Frag. Phil. Græc.* i. 68) among the commentators on Empedocles. But some authorities, as Karsten (*Phil. Græc. Vet. Rel.* ii. 248) and Lommatschius, suppose that by ῥινῶν Empedocles meant the skin, and that he was speaking of a supposed cutaneous respiration (cf. Introd. pp. 20, 21); and this view has been adopted by Zeller (*Pre-Socrat. Phil.* ii. 165) and others. There appear to me, however, to be no sufficient reasons for holding Aristotle to have misinterpreted Empedocles. The language used by Empedocles, e.g. Αἰθὴρ παφλάζων καταβήσεται οἴδματι μάργῳ, is very hyperbolical even when applied to ordinary nasal respiration, unless we suppose him to refer to snoring, but is utterly inapplicable to the supposed passage of air through the pores of the skin, noiseless and imperceptible.

67. I take ἄλοξι to mean the nasal channels or passages, and

πυκναῖς to be close-set, alluding to their close contiguity; possibly, however, it may mean 'secret,' or we should read πυκνοῖς and take it with στομίοις.

68. The clepsydra of these lines is clearly the same implement as the clepsydra of the *Problems* (xvi. 8). It is usually supposed to be the water-clock known by this name. If so, the water-clock of the time of Empedocles and Aristotle must have differed much in form from those of later days. For, putting aside such complicated instruments as that described by Vitruvius, with its cogwheels and other refinements, the ordinary clepsydra appears to have resembled one of our sand-glasses, or even to have been a simple amphora with a hole in the bottom, through which water was discharged when the amphora was in an upright position (cf. King, *Early Christ. Numismatics*, p. 113). But the clepsydra of Empedocles and of the *Problems* was a funnel-shaped vessel, of which the wider end was covered with a much-perforated disc. It resembled, in short, a funnel-strainer, such as is used to decant wine and keep back any dregs; or the removable nozzle or rose of a common watering-pot, the narrow tube being the αὖλος, and the perforated disc the ἤθμος. It has, indeed, been suggested that clepsydra was the name by which the Greeks designated such a nozzle or rose. Thus Denis Petau in a passage quoted by Sturz (*Emped.* ii. 430) says that the name was applied 'ad ea vasa quibus ad perpluendas hortorum areolas utimur;' and a still older writer, Pietro Vettori, also says (*Var. Lect.* xxxii. 1) 'existimo vocatum quoque fuisse a Grecis hoc nomine vas illud quo mos est hortos irrigare.' I cannot find that their opinion rests on any better foundation than conjecture. The conjecture, however, seems to me far from improbable, and perhaps the more so because I recollect myself, as a child, playing with the rose of a watering-pot just in the way the girl is represented as doing in the verses of Empedocles.

69. Holding it, of course, upright, with the perforated disc downwards. If held slantingly the air escapes as stated in the *Problems* (xvi. 8, 3).

70. Bringing, of course, the vessel out of the water in an upright position, and with the perforated disc downwards.

71. For ἰσθμοῖο I read ἠθμοῖο.

72. The vague word τέρεν, when applied to fluids, as tears, water, blood, apparently means clear, limpid, free from clot. In this place, then, as applied to blood, it would correspond to Shakespeare's 'thin and wholesome blood' (*Hamlet*, i. 5, 70).

73. The posterior nares.

74. By 'a certain heat,' I take it, is meant a certain quality or kind, not a certain quantity, of heat. For in a notable passage (737, a, 5. *De Gener.* ii. 3, 12) Aristotle says that the heat to which the vital activities of animals are due is not ordinary heat or fire, nor derives from such

fire its efficacy, but is a nobler kind of heat akin to, or identical with, that of the heavenly bodies. See Introd. p. 8.

75. By *αἱ ἀνατομαί* Aristotle sometimes means actual dissection (*e.g.* 677, a, 9, and 764, a, 35. *De Part.* iv. 2, 6, and *De Gen.* iv. 1, 10), and sometimes his treatise on anatomy (*e.g.* 497, a, 32, and 746, a, 14. *Hist. An.* i. 17, 19, and *De Gen.* ii. 7, 6). Here he may mean either, but I have taken him to mean actual dissection.

76. See Note 3 and Introd. p. 3.

77. See *Life and Death*, ch. 5, pp. 68–70.

78. Such I take to be the meaning of this obscure and probably corrupt sentence. A heated body cools more rapidly when broken up into pieces than when left entire, because the subdivision exposes a greater surface to the air; and Aristotle supposes the same to be the case when an animal that retains life after division, such as a centipede, has been cut in segments. This tallies with the passage (531, b, 31. *Hist. An.* iv. 7, 3) in which it is said that insects of very cold nature cannot survive division.

79. Cf. Note 34.

80. The function which in the higher animals devolves on lungs or gills is, as a matter of fact, performed by the general surface in animals without special respiratory organs. Cf. Introd. p. 37.

81. That large-sized animals are, as a general but by no means universal rule, longer-lived than small animals, and sanguineous animals or vertebrates than invertebrate, is set forth more fully in the little treatise *De Long. et Brev. Vitæ* (466, a, ch. 4). Elsewhere (777, a, 32. *De Gener.* iv. 10, 1–3) it is further noted that there is a connection between long life and a lengthy gestation period. 'As a general rule the period of gestation is in each animal proportionate to its length of life; for it is reasonable that the development of animals that live long should also be lengthy. Still, long gestation cannot be the cause of long life, for it is not invariably associated with this, but only generally. Again, the larger and the more perfect of the sanguineous animals are long-lived, but nevertheless do not invariably surpass other animals in this respect. For, with the exception of the elephant, man has the longest life of all animals concerning which we have trustworthy knowledge, and yet man is of smaller bulk than the animals with manes and than many others. The cause of any animal being long-lived is that its composition is in close harmony with that of the environing air, while there are also other physical characters that are indications of longevity. The period of gestation is determined by the bulk of the generated product; for, as elsewhere so in animals, constructions of large size cannot be completed in a short space of time. On this account horses and animals akin to them, though their life is shorter than that of man, have a longer gestation period, &c.'

As to the agreement of these views with those of modern physiology, see Introd. p. 15. As regards the facts, vertebrates are as a rule, so

far as our scanty knowledge goes, longer-lived than invertebrates; and, among vertebrates, the mammals are the most highly organised, and on the average live longest. Of these, again, those that are believed to have the longest span are the whale, elephant, rhinoceros, hippopotamus, and camel, all animals of huge bulk; while among birds the raven, goose, falcon, parrot, and among reptiles the crocodiles and tortoises, all of comparatively large bulk, are those that are said to live longest. Trees, again, are as a rule larger and longer-lived than shrubs, and these than herbs. See Ray Lankester, *Comp. Longevity*, pp. 55–61.

82. Cf. Introd. pp. 36, 37, and Note 10 to ii. 16 in my translation of the *De Partibus*.

83. John Hunter (*Works*, iv. 427) thought that bees were probably the only insects that developed heat; an error corrected later on by Newport (*Phil. Trans.* 1837).

84. Virgil also (*Georg.* iv. 207) gives a life of seven years to bees. Aristotle elsewhere (554, b, 6. *Hist. An.* v. 22, 13) says they sometimes live for seven years, but usually for six only. Réaumur (*Hist. d. Insectes*, v. 715) thought they scarcely lived more than a year. It is held by modern beekeepers (Girard, *Les Abeilles*, pp. 111, 123) that though queens may live for three or four, or occasionally five, years, ordinary workers live only for from six weeks to about eight months; those hatched in spring and summer, the season of hard work, having the shortest span of life, and those hatched in late autumn having the longest. The facts are ascertained by giving a Ligurian queen to a hive of black bees, and noting when the black bees are replaced by bees with Ligurian characters.

85. As to the 'innate spirit,' see Note 11 to ii. 16 of my translation of the *De Partibus*. As to the sounds made by insects, see Note 87. As to their respiration, see Introd. pp. 36, 37.

86. Cf. Note 41.

87. Authorities are not yet in full agreement on all points as to the production of sounds by insects. Adopting, however, the usually accepted views, we may group the sounds and the modes in which they are produced under five headings: Firstly, *ticking* or *rapping*, produced by striking a hard substance with the mandibles, *e.g.* Anobium or the death-tick. Secondly, *stridulation*, produced by rubbing one part of the chitinous integument against another specially modified for the purpose, *e.g.* grasshoppers and crickets. Thirdly, *humming* and *buzzing*, mainly produced by the forcible expulsion of air through the stigmata or spiracles, some of which, according to Landois, have in their orifices certain chitinous plates, that are set in vibration by the outgoing current of air, *e.g.* bees and wasps. Fourthly, so-called *singing*, produced by certain special membranous drums, set in vibration by muscles; or, according to Landois, produced by discharge of air from the metathoracic spiracles, and only intensified by the drums,

e.g. cicadæ. Fifthly, the sound produced by rapid vibration of the wings, which contributes to the humming or buzzing of the third method.

Of the first of these five modes Aristotle makes no mention. The second was recognised by him and noted in the *Hist. An.* (iv. 9, 4; 535, b, 12): 'The sound made by grasshoppers is produced by friction with the large hind legs.'

The sounds of the third and fourth kind were distinguished by him, but supposed to be produced by one and the same mechanism, namely by vibration of drums, as in cicadæ, or of membranes, answering to drums, in bees and other humming insects. And, if Landois be right, Aristotle was correct in so thinking; his error consisting in his having supposed that the drums or analogous membranes were set in vibration by air confined inside the insect's body, and not by air discharged through spiracles, of whose existence he was ignorant, as was every one until Malpighi discovered them in 1669.

The fifth mode of sound-production was also recognised by Aristotle, *e.g.* 'If any one holds a wasp by the legs and allows it to buzz with its wings' (628, b, 19. *Hist. An.* ix. 41, 15).

88. The male cicadæ alone sing, and in the females the drums are imperfectly developed. Hence the well-known line of Xenarchus, 'Happy the cicadæ live, for they all have voiceless wives.' As to the drums of the cicadæ, see Introd. pp. 36, 37.

89. This paragraph seems misplaced. It would come more fitly somewhere towards the beginning of the next chapter, where sanguineous animals are discussed. Here it breaks up unmeaningly the consideration of bloodless animals, and especially of insects.

90. Cf. Note 44. 91. Cf. Note 41.

92. For *ὑγροῦ* I read *ὑμένος*. The insect immersed in water dies, because its spiracles are obstructed so that it can no longer breathe, and it recovers, when taken out and warmed, because the water evaporates and leaves the spiracles again free. But if the fluid be oil, which will not evaporate, the insect does not recover. The fact was known to Aristotle (605, b, 19. *Hist. An.* viii. 27, 3), and explained by Malpighi (*De Bombyc.* p. 14).

93. That is, take it as fishes do in order to bathe the gills, and not as whales and porpoises, or, as Aristotle supposed, as poulps and crustacea (see Note 120), merely as an incidental accompaniment of the prehension of food.

94. The reason why these animals can live out of water so much longer than ordinary fishes is presumably that their gills are more perfectly secured against desiccation, and that their vital changes are much less energetic, so that they have less imperative need of oxygen. Substitute throughout this treatise 'need of oxygen' for 'need of refrigeration,' and Aristotle's observations will be found to be remarkably just.

95. I omit οἱ before πολλοί, for Aristotle cannot have said that *most* fishes present the phenomenon in question. Eels often bury themselves in the mud, and are dug up alive on the banks of rivers. But as Aristotle, when describing the habits of eels (592, a. *Hist. An.* viii. 2), does not mention this, he is more probably alluding to certain Indian fishes (*Ophiocephalus*) that, in common with other tropical freshwater fishes, act in the same way. Of these he may have acquired knowledge through Alexander's expedition. Or he may refer to the fishes that Theophrastus mentions as being dug up alive in Pontus and in Paphlagonia, or as living, when the river has dried up, in wet holes in the ground in Babylonia (Theoph., Schneider's ed., i. 827, 829, 826).

96. 'Internally viviparous' is equivalent to Mammalia, whose ovum was unknown to Aristotle. It excludes all ovo-viviparous animals which Aristotle called 'externally viviparous but internally oviparous.'

Under the term Selachia Aristotle includes all the cartilaginous fishes, among which he erroneously classed the Lophius. All these, he often says, are, with the exception of Lophius, ovo-viviparous, that is to say, they retain their ova within the body till hatched. This, however, is not the case with all of them ; for the oviparous dog-fishes and rays are exceptions. See as to this subject my translation of the *De Partibus*, iv. 1, note 5, and iv. 13, note 5.

97. Cf. Note 44. Aristotle here says 'in most cases,' admitting exceptions, whereas before he had said 'all.' There are, of course, great differences in the degree of sponginess presented by the lungs of ovipara.

98. Aristotle is clearly here writing carelessly. The infrequent respiration cannot be the consequence of the spongy character of the lung ; but, in common with that structure, is an adaptation to the scanty need of oxygen, or, as Aristotle would say, of refrigeration.

99. In the *Hist. Animalium* (ii. 14, 1 ; 505, b, 6) Aristotle says that snakes are mostly terrestrial, a few only living in fresh water, but a considerable variety in the sea. By these last he probably means the Indian Hydrophides, of which, as of certain Indian fishes (cf. Note 95), he may have heard owing to Alexander's expedition. The freshwater snakes probably mean the common ringed snake (*Natrix torquata*), which is 'extremely fond of water, taking to it readily, and swimming with great ease and elegance, having head and neck above the surface. It is very probable that it resorts to the water in search of frogs' (Bell's *Brit. Reptiles*, p. 54).

100. I have here rendered Emydes by 'freshwater tortoises.' Cf. Note 45.

101. It need hardly be said that this is not the case at any rate with frogs.

102. Cf. Note 96. There seems no special ground for mentioning the Selachia here more than any other group of fishes. Aristotle seems to imagine that there is some mysterious correlation between feet and

lungs, and between fins and gills. Feet and lungs are adaptations for terrestrial life, and are consequently very generally found associated in the land vertebrates; while gills and fins are adaptations for aquatic life, and are consequently very generally associated in aquatic vertebrates.

103. Resembling wings rather than legs or feet in form because of their expanded surface, and still more resembling them in their motion, so that Aristotle elsewhere (644, a, 12. *De Part.* i. 4, 1) expresses surprise that some common name has not been devised to comprise animals that swim and animals that fly. In Plato's *Sophistes* (Jowett's Transl. ii. 479) we read 'of swimming animals one class live on the wing, and another in the water.' Flying fishes can support themselves for a short space in the air by means of their fins, and there are both insects and birds that can use their wings for swimming. Thus Darwin says of the jackass penguin (*Voyage of 'Beagle,'* ch. ix.) 'In diving, its little wings are used as fins;' and Wallace (*Darwinism*, p. 116) says of the dippers that they 'have the extraordinary power of flying under water.' The Greek term for a fin (πτερύγιον) means 'a little wing.'

104. The Perennibranchiate Amphibia had not as yet 'come under observation.'

105. Cf. 695, b, 25. *De Part.* iv. 13, 7. It is strange and yet, as it appears to me, indisputably true that Aristotle was perfectly ignorant of the fact that tadpoles are the larval forms of frogs and newts. For it is impossible that he can have known it and yet made no mention of what would have seemed to him, as indeed it is, a most extraordinary phenomenon.

106. Aristotle neither knew of the Dipnoi among fishes, nor of the Amphipneusta among amphibians, in both of which groups gills and lungs are coexistent.

107. Similarly Aristotle states elsewhere, with much foundation of fact, that no animal has more than one adequate instrument of defence. See my translation of the *De Partibus*, iii. 2, note 9.

108. Although Aristotle here gives these exceptions, and repeats them and others elsewhere (661, b. *De Part.* iii. 1, 2; and 659, a, 22. *De Part.* ii. 16, 8), he held that the general rule was 'a separate organ for each separate office.' For the doctrine of the physiological division of labour, which Milne Edwards thought he was himself the first to enunciate (*Leçons s. l. Phys.* i. 16), was distinctly formulated by Aristotle again and again. Thus: 'It is better, when possible, that one and the same instrument shall not be made to serve several dissimilar uses . . . Whenever, therefore, Nature is able to provide two separate instruments for two separate uses, without the one hampering the other, she does so, instead of acting like a coppersmith, who for cheapness makes a spit and lampholder (ὀβελισκολύχνιον) in one. It is only when this is impossible that she uses one organ for several

functions' (683, a, 23. *De Part.* iv. 6, 13; and note 9 in my translation of that chapter).

109. 'In all fishes the teeth are sharp; so that these animals can divide their food, though imperfectly. For it is impossible for a fish to linger or spend time in the act of mastication, and therefore they have no teeth that are flat or suitable for grinding; for such teeth would be to no purpose' (675, a, 5. *De Part.* iii. 14, 12). As a matter of fact the sharp oral teeth of fishes serve to seize and hold their food rather than for its comminution, though the pharyngeal teeth, with which many are provided—but of whose existence Aristotle was probably ignorant, as he makes no special mention of them—often effect a more or less perfect trituration.

110. As all animals, and indeed all living things, according to Aristotle, need refrigeration to some extent, he must here mean special organs of refrigeration, and I have consequently introduced these words.

111. And therefore, he implies, in a position which favours the intrusion of food. 'The windpipe lies in front of the œsophagus, although this position causes it to be some hindrance to the latter in the act of deglutition' (664, b, 3. *De Part.* iii. 3, 10). See note 5 to that chapter in my translation of the *De Partibus*, for a supposed explanation of the awkward position.

Aristotle somewhat over-estimated, as most later physiologists have done, the necessity of the epiglottis. On the other hand some moderns have gone to the opposite extreme. Thus Magendie assigned to it a very subordinate part in the exclusion of food from the air-passages, and thought that an animal was very little inconvenienced by its removal. But Longet showed that this was erroneous as regards fluids, though it was to a certain extent true as regards solids.

112. See Introd. p. 38. Mammals alone have an epiglottis. In other pulmonate vertebrates the opening into larynx and trachea is closed simply by constrictor muscles. Cf. 664, b, 25. *De Part.* iii. 3, 14,

113. See Note 109.

114. The oral teeth of fishes vary much in form, but usually are elongated cones, more or less sharp-pointed, and slightly curved inwards, so as to be suitable for holding slippery prey. But there are many exceptions, and many more than are recognised by Aristotle, who says (675, a, 3. *De Part.* iii. 14, 11) 'Fish are provided with teeth which are almost invariably serrated. For there is but one small group in which it is otherwise. Of these the fish called Scarus (*the parrot-fish*) is an example.' It seems strange that Aristotle should not have noticed the tesselated teeth of certain rays and skates with which he was well acquainted; but probably he did not regard these as teeth, but as indurated lips.

115. See note 38 to iv. 3 in my translation of the *De Partibus*, for Aristotle's views concerning Cetacea.

116. This statement is often repeated by Aristotle (*e.g.* 537, b, 3—566, b, 15—589, b, 9. *Hist. An.* iv. 10, 11—vi. 12, 4—viii. 2, 6). Whether dolphins really snore when asleep I do not know; but their snorting is especially heard at night. Cf. Bates' *Amazon*, 3rd ed. p. 75.

117. When in the net, so that they are kept under water and cannot rise to the surface, they die, and this can only be, says Aristotle, because they are animals that breathe, and consequently require to come to the surface.

118. Cuvier (*Règne Animal*, i. 285) gives the same account as Aristotle of the use of the blowhole, and it is still the popularly received view. But it is now known by naturalists to be erroneous. The real use of the blowpipe is to provide a more perfect safeguard, than the epiglottis by itself would do, against the intrusion of water into the air-passages. For the cetacean larynx is lengthened out into a rigid tube which is thrust up into the blowpipe, so as completely to shut off the air-passages from the cavity of the mouth; and the blowing or spouting is due, not to the expulsion of water from the mouth, but to spray and condensed vapour driven up by the force of expiration when the animal rises to the surface.

119. Aristotle apparently means that if the blowhole was intended to allow of the escape of heat from the blood, that is to say if it were an instrument of expiration, it should lead to some organ such as the lung, which is rich in blood. This, however, it does not do, but is nearest to the part which has least blood and least heat, viz. the brain.

120. As to the characters and divisions of the malacostraca or crustaceans, see *De Part.* iv. 8, note 1, in my translation; and, as to the malacia or cephalopods, iv. 9, note 1.

121. By the flaps or overfolds (ἐπιπτύγματα) I understand the branchiostegites, or plates that cover in the branchial chambers, though possibly they may be the same as the ἐπικαλύμματα, mentioned later in this note. The shaggy appendages (τὰ δασέα), which one is tempted to interpret in this place as the gills, must, I think, be—as in the *Hist. An.* (iv. 2, 13; 526, a, 27)—the shaggy processes of the various organs of manducation.

It is not through the mouth, as seems here implied, that crustacea take in or discharge the water. In lobsters, crayfishes, and crabs, water is admitted into each branchial cavity by a cleft between the great lateral flap of the carapace (ἐπιπτύγμα) and the animal's body. This cleft is of considerable length in lobsters and crayfishes, but in crabs is reduced to a comparatively small slit at the base of the great claws and not far behind the mouth. The water that has made its entrance by this inlet, after bathing the gills, is discharged by a canal which opens externally just in front of the mouth and behind the eyes.

Aristotle (*Hist. An.* iv. 2 and 3) had made out both this inlet and outlet, and knew that they were distinct from the true mouth, that is,

from the orifice by which food is admitted, and he describes their position with some accuracy. The water, he says, is, in the crab (526, b, 18. *Hist. An.* iv. 2, 19), admitted in the neighbourhood of the mouth (παρὰ τὸ στόμα), and is discharged by the upper (i.e. *anterior*) channels of the mouth (τοὺς ἄνω πόρους τοῦ στόματος), which are immediately behind the eyes (527, b, 18. *Hist. An.* iv. 3, 5). From this description of the position of the outlet, it appears that Aristotle considered the whole of the quadrate space, in which are situated both the aperture for the admission of food and the aperture for the discharge of water, to constitute the mouth ; and when he says 'the anterior passages of the mouth,' he means, as we should say, the passages *in front of the mouth.* Indeed, he speaks of one of these apertures as 'a small part of the mouth' (526, b, 19. *Hist. An.* iv. 2, 19). Moreover Aristotle not only knew of these distinct inlets and outlets for water, but also knew that they were closed and opened alternately (527, b, 19. *Hist. An.* iv. 3, 5) so as to determine the direction of the current.

The water is driven through the chamber by the action of a curious process (*scaphognathite*) given off from the second maxilla ; and, in order to effect this, the second maxillæ are in constant motion. This motion was noted by Aristotle (526, a, 27. *Hist. An.* ii. 2, 14) in lobsters, but he did not know its purpose. Neither did he know of the gills, or, if he knew of them, recognise their character ; for, when he speaks of certain shaggy processes (τὰ δασέα) of branchiform aspect which are round the mouth, he clearly alludes to the hairy palps and processes connected with the organs of manducation.

He thought that the water was admitted into the branchial chamber not for respiratory purposes, or, as he would say, for refrigeration, but simply to prevent its going into the mouth proper with the food ; and he pictured the process in the following way : When a current of water with floating food comes to the animal's mouth, the food is admitted, but the water is thrust aside and diverted into the special inlet for it near the mouth by certain opercula (ἐπικαλύμματα), by which he must mean the quadrate plates that are given off from the external maxillipedes, and fit over the mouth like a pair of folding doors, and are of course moved from it when food is taken in. Cf. Huxley, *Crayfish*, p. 275.

In the cephalopods also it is not by the mouth that the water is admitted, but by a large opening leading into the branchial chamber ; and Aristotle's more accurate language in the *Hist. An.* (iv. 1, 11 ; 524, a, 10) seems to recognise this. 'These animals, when their mouth is engaged in the reception of food, take in water by the abdominal sac (τῷ κύτει), and then discharge it by the pipe.' A fair enough statement, excepting that it supposes the water to be taken in only at the time of feeding. Aristotle had noticed the gills in these animals, but did not recognise their use. 'These animals,' he says, 'have also in

their body certain hairlike or filamentous processes' (τριχώδη ἄττα) 524, b, 21. *Hist. An.* iv. 1, 20.

122. The mammalia are, on the average, of considerably larger size than other existing vertebrates, and the vertebrates generally than the invertebrates.

123. Cf. Note 6.

124. I suspect we should read καθάπερ οὐδ' ὁτιοῦν, *i.e.* 'more than any other.'

125. The text is clearly corrupt. I omit καὶ τὰ, and substitute δεῖ. Aristotle argues that, final causes apart, the structure of an organism can only be such as its ultimate material composition and the conditions under which it originates will allow; and that we must suppose that a composition mainly consisting of cold and fluid matter, or development without adequate heat, is incompatible with the formation of a lung. Nature, in forming an organism, gives it the best structure she can; but that structure may not be the best ideally, but the best only that the material conditions permit.

He further argues that the materials of an organism can only be such as are to be found in the place where it originates, and that consequently an organism that originates in the water must of necessity be made of water, that is, must have a preponderance of cold and fluid in its composition; and that thus may be explained the absence of lungs from such animals as fishes, although, from the point of view of final causes, the presence of such organs might possibly be desirable.

As the materials of any organism must of necessity be those of the place where it originates, there must in all cases be a correspondence in composition between an organism and the medium in which it lives; and it is thus that Aristotle would explain the harmony between an organism and its habitat, and the disturbance in its well-being that often ensues on its transplantation or migration into strange surroundings.

126. This doctrine of Empedocles is mentioned also by Theophrastus (*De Caus. Plant.* i. 21, 5 and 22, 2). See also Plutarch (*Plac. Phil.* 4, 22).

127. It is much to be regretted that we have not got the actual words of Empedocles which might have enabled us to ascertain what he exactly meant by saying that water animals originated on land. We may, however, feel certain that he could not have meant crudely that an animal, such as an ordinary fish, utterly incapable of living in air, and without power of terrestrial locomotion, originated on land and then made its way to sea or river. Possibly he may have noticed that eels, though fishes, can live in air for a considerable time, and can travel over dry ground, and have supposed that this was the original condition of all fishes. Be this, however, as it may, the view propounded by him is exactly the opposite of that generally entertained by modern naturalists. They hold that the primal ancestors of all land animals, and probably of all land plants, were aquatic; and that

certain of their descendants became adapted for terrestrial life by gradual modification of structure. Some of these modified descendants, however,—as the whales and seals—afterwards reverted to their ancient habitat, and may thus be said, with Empedocles, to have migrated from the land to the water.

The doctrine that all animals originated on land is repeated by Lucretius, who, however, does not explain how, in that case, fishes got from land to water, though he points out the impossibility of terrestrial animals having migrated from water to land :

> Nam neque de cælo cecidisse animalia possunt,
> Nec terrestria de salsis exisse lacunis.
> Linquitur ut merito maternum nomen adepta
> Terra sit, e terra quoniam sunt cuncta creata (v. 793).

128. Aristotle is himself open to a similar accusation. Cf. Introd. p. 9. As to his tests of vital heat, see my translation of the *De Part.* p. xxiii.

129. The text is very obscure, partly from its extreme condensation ; but I take it that with τὸ ζητούμενον must be understood μέτριον (just as a little way on, in τοῦτο δεῖ ζητεῖν, the τοῦτο = μέτριον), and that 'the cause of which Empedocles speaks' is the final cause of the medium, which was in his opinion the correction of the material composition of an organism by its own opposite composition.

This doctrine, says Aristotle, cannot possibly be true. An organism can only come into being and exist in a medium in which its own material constituents predominate. But there is this amount of truth in the doctrine of Empedocles : adventitious conditions of the organism can be corrected by opposite conditions in the medium. A bird, for instance, or a fish can only live in a medium corresponding in composition with itself—the bird in air, the fish in water. But supposing some adventitious cause—say, disease—to produce abnormal exaltation or depression of the temperature of the animal, it will derive benefit by migration to cooler or warmer regions within the limits of its proper medium, where its abnormal condition will be corrected by the opposite condition of the environment ; or, independently of migration, the correction may result from change of temperature induced by change of season, which affects all media alike, whether air, water, or earth.

130. Both ἕξις and διάθεσις (8, b, 28. *Categ.* 8) are qualities (ποιότητες) or conditions of the body that are not necessary results of its material constitution, inasmuch as they can be acquired or removed while that remains unaltered. They differ from each other in the tenacity of their respective holds on the body. A διάθεσις is temporary, fugitive, easily displaced (εὐκίνητος), but by frequent repetition may become more deeply engrained and be converted into a ἕξις, difficult to eradicate (δυσκίνητος). No English equivalents for these words can be given. Perhaps ἕξις might be approximately rendered 'habit of body,'

and διάθεσις be retained as diathesis ; but, unfortunately, diathesis has been used by medical writers rather as an equivalent of ἕξις, as in 'the gouty diathesis.' I have therefore rendered the terms as 'conditions, persistent or temporary.'

131. The four ultimate forms of matter, of combinations of which all earthly things consist, were, according to Aristotle, solid, fluid, hot, and cold, though here, for brevity, he only mentions the two first. See *De Part.* ii. 1, note 3 in my translation. In the next line I omit the words καὶ ψυχροῦ.

132. *Hist. An.* i. 17 and iii. 2–3. See also, as to Aristotle's views concerning heart and lungs, *De Part.* iii. note 9, and iii. 4, note 23, in my translation.

Aristotle does not mean that there are open passages by which air can pass directly from lung to heart, but merely that there are blood-vessels connecting the heart with the lung, and allowing the air to pass through their walls from the contiguous air-tubes. 'There are also ducts (i.e. *the pulmonary blood-vessels*) which lead from the heart to the lung, and there divide and subdivide, their branches accompanying the branches from the windpipe. But there is no communication between the two (οὐδεὶς δέ ἐστι κοινὸς πόρος). Notwithstanding this, however, air can pass from the latter (i.e. *the bronchial tubes*) into the former (i.e. *the pulmonary vessels*), owing to the close contact in which the two lie (διὰ τὴν σύναψιν), and be transmitted to the heart' (496, a, 31. *Hist. An.* i. 17, 6).

133. Or perhaps 'resort must be had to dissection for ocular demonstration.' Cf. Note 75.

134. 507, b, 3. *Hist. An.* ii. 17, 1.

135. The substratum of fact for this fanciful notion is that in fishes the aortic bulb (see next Note), which Aristotle takes to be the apex of the heart, runs directly forwards, pointing therefore to the head ; and the head, closely amalgamated with the body, can of course only move in the forward direction ; but in mammals the apex of the heart inclines towards the sternum, towards which the head also moves when nodded.

136. The heart of almost all fishes terminates anteriorly in an aortic bulb. (This is Aristotle's apex, and considered by him to be part of the heart.) From the bulb is given off in the middle line a stout vessel, the branchial artery. (This is Aristotle's largest tube or duct.) From this central branchial artery are given off on either side the aortic arches. (These are the smaller ducts which run to the extremity of each gill.)

Aristotle speaks of these aortic arches as given off on either side of the heart itself. Probably the fish he examined was a ray, and here the branches which supply the three hinder pairs of gills are given off so close to the bulb that they may almost be said to come from it ; and the bulb, as already mentioned, was held by Aristotle to be part of the heart itself.

137. Cf. Introd. p. 44. The words introduced in brackets are required to give meaning to ἑκάτερον, and are further justified by the passage in *Hist. An.* (viii. 2, 38 ; 592, a, 19–23). 'Eels and other fishes are suffocated if kept in a small quantity of water that is unrenewed, and the same happens to air-breathing animals when shut up in a limited quantity of air.' Perhaps ἢ ὕδατι should be read after ἀέρι.

A line further on the words τὸ αἷμα are unmeaning, and should be omitted or τοῦ αἵματος substituted.

138. Cf. Note 23.

139. This passage with some others (503, b, 23 ; *Hist. An.* ii. 11, 11. 765, a, 26 ; *De Gen.* iv. 1, 23. 774, b, 31 ; *De Gen.* iv. 6, 7) show that Aristotle occasionally vivisected animals. The presence of the carapace is not of the importance Aristotle seems here to attribute to it. He does not appear to have observed that the heart itself sometimes continues to beat after removal, and even its separated pieces. Haller (*El. Phys.* i. 436) cites various instances of animals, both cold- and warm-blooded, that ran about and uttered sounds after removal of the heart, and among others states, on the authority of J. B. Caldesi, that a tortoise 'per quadraginta horas ambulavit' after such operation.

140. This passage with a portion of the next chapter are the only parts of the treatise that deal specially with Youth and Old Age. This seems quite incompatible with Weise's subdivision, according to which the first six chapters form a separate opusculum on Youth and Old Age.

141. Birth is a very inadequate rendering of Aristotle's *genesis.* For by birth is ordinarily understood the separation of the young from its mother's body, and the commencement of independent existence ; but Aristotle's *genesis* goes back through all the series of earlier processes to the first formation of the unfecundated germ. The animal soul, he says, is imparted to the germ by fecundation ; but the unfecundated germ must be held to possess some sort of nutritive soul, derived from the mother, inasmuch as it is capable of a certain amount of development (736, a, 32. *De Gen.* ii. 3, 3–4).

142. Aristotle finds the cause of senile decay in the gradual dissipation of heat and fluid, the dissipation of fluid being indeed ultimately loss of heat. For it acts by causing desiccation and consequently induration of the lung, which is thus rendered unable to perform its office, the *caloris preservatio per refrigerium.* See Introd. p. 41.

143. As Aristotle has not yet dealt with the several topics here mentioned, it is plain that τοῦτον τὸν τρόπον must refer—in accordance with the very common usage of οὗτος—to what follows, not to what has gone before. But it is to be noted that the discussion of the topics enumerated does not follow at once, as τοῦτον would lead us naturally to expect, but is only entered on after a long interposed passage—which seems quite out of place—concerning palpitation and pulse, neither of these being included in the subjects which Aristotle

has said that he is now going to discuss. I am therefore inclined to believe that the whole of Chapter XX. is a later interpolation.

144. The distinction between residual matter and that derived from body-waste is elaborated in the *De Generatione* (i. 18 ; 726, a).

The causes of disease recognised by Aristotle seem to have been senile decay (Note 142), exposure to excessive cold or heat, and the retention in the body of the products—always noxious—of body-waste (*συντήγματα*) or of residual substances (*περιττώματα*), in which were included all excretions and secretions, and also such surplus of nutriment as is not required for the maintenance of the fabric.

145. Cold and terror have been everlastingly coupled together by writers of all ages, e.g. Virgil, *Æn.* 3, 40 ; *Faery Queen*, i. 9, 25 ; *Hamlet*, i. 5, 16. The notion is of course founded on the fact that many of the external signs of fear—as pallor, shivering, chattering of teeth, erection of hair—are identical with the signs of intense cold.

146. In the *De Partibus* (iii. 6, 5 ; 669, a, 20) Aristotle says that palpitation from terror occurs 'so to speak' in man alone.

147. Sometimes the food is said to reach the heart as a fluid, sometimes, as later on in this chapter, as a steam or vapour.

148. Cf. Note 25. From this passage and another in the *De Partibus* (iii. 4, 12 ; 666, a, 10) it would appear that Aristotle supposed the heart and the blood within it to be formed simultaneously, which is indeed the case. For the heart when it first appears is a compact mass of cells, of which the outer coalesce to form the walls, while the inner separate and form the first blood corpuscles. See Introd. p. 4.

149. It is not clear whether Aristotle means that the pulse is stronger in youth than at a later age, or that it is more frequent. The latter is the case ; for, according to Quetelet, the pulse in a child shortly after birth averages 44 per minute, at five falls to 26, at fifteen to twenty to 20, at twenty to twenty-five to 19, and at thirty to 16, after which it becomes slightly more rapid.

150. Aristotle's account of the pulse and its relation to inspiration is so vague and obscure that any attempt to state his view must be to some extent conjectural. He had to explain two pairs of unceasing alternations : one, the alternation in lung and thorax of expansion with subsidence ; the other, the alternation in heart and vessels of beat with pause. As he was entirely ignorant of muscular contraction, the only force to which he could attribute these movements was the cardiac heat ; and consequently he had to explain how this force could bring about the two alternations, and how, moreover, the two alternations, though due primarily to one and the same cause, came nevertheless to be asynchronous, pulsation being very much more frequent than respiration. It is true that Aristotle, strangely enough, makes no mention of this asynchronism, though it is noted in the spurious treatise *De Spiritu* (4, 6 ; 483, a, 1) ; but it is impossible to suppose that he was ignorant of this very obvious fact, which must

indeed have forced itself on his observation every time emotion, or unwonted effort of exercise, made his heart's action more than usually perceptible to him. It must, consequently, be assumed that his explanation included this palpable asynchronism.

The mode in which he pictured the processes to his mind must, then, have been much as follows: When the heat, perpetually generated in the heart, has reached a certain degree of intensity, it causes lung and thorax to expand. Cold air rushes into the expanded lung, cools the excess of cardiac heat, and lung and thorax in consequence subside; and so on in constant alternation.

But though the cardiac heat is reduced by the inspired air to a point that is insufficient to maintain the expansion of the lung, it is never reduced to a point below that which is sufficient to keep the blood in the heart in a state resembling ebullition—a state, that is, in which its bulk is augmented (*ὄγκωσις*) with a formation of steam (*πνευμάτωσις*) and a boiling over into the blood-vessels (*ἔκπτωσις διὰ τῶν ὁριζόντων ἐν τῇ ζέσει*). This, then, always goes on in the heart, alike during inspiration and expiration. The beat of the heart is caused by the distension of its outer coat by the swollen blood, and the simultaneous pulse in the vessels by the discharge into them of the steam and overflowing fluid; but by such discharge the distension of the heart is relieved, and this condition, when its wall momentarily subsides and the blood, replenished by fresh material from the stomach, is preparing for another expansion, corresponds to the period of pause.

It is to be noted that, according to Aristotle's view, the beat of the heart corresponds to its dilated condition, not, as is generally held by modern physiologists, to its contracted or systolic condition.

151. Before *προσδέξασθαι* read *τοῦ*. In comparing the heart to bellows, Aristotle implies that the blood, or fluid on the way to become blood, is sucked in by that organ as well as expelled by it. What he had not made out was that there were separate vessels for the in-current and the out-current.

152. The ancients used single bellows made as ours, and also double bellows—a *pair* of bellows—consisting of two bags, each with its separate inlet, but with a common nozzle or outlet. See Smith's *Dict. of Antiq.* under *Follis.*

153. The heart with the nutritive principle must be in the centre of the lungs in order that it may be equally cooled on all sides.

For *φυσικῆς*, which seems unmeaning, I have adopted an emendation suggested to me by Mr. Poste, and read *ψυκτικῆς*. Another possible emendation would be *φυσητικῆς*. In the next line it would be better, though not absolutely necessary, to read *πλέονος γενομένου* (scil. *τοῦ θερμοῦ*).

154. For *τοῦ τοιούτου μορίου*, which is unintelligible, I read *τὸ τοιοῦτον μόριον*. The passage is somewhat obscure; but, as I understand it, the thorax is said to expand in consequence of the expansion

of the bellows-like lung, which in its turn has been made to expand by the internal heat. For εἰσφέρειν in the next line I read εἰσρεῖν.

155. Aristotle here speaks of the water as not only discharged but admitted by the gill openings, which is not the case, save, exceptionally, in such fishes as the lamprey and the hag-fish. It is admitted in most fishes by the mouth, and in Selachia by special spiracles. These spiracles are not mentioned by Aristotle; but that the mouth is the ordinary inlet is stated in the *Hist. Animalium* (ii. 13, 4; 504, b, 29). 'The gills form in fishes a distinctive organ, and through them they discharge the water, which they have taken in by the mouth.'

156. The channels (πόροι) are of course the branchial vessels which Aristotle supposes to carry blood in each direction between heart and gills. See Note 151.

157. That κομψοὶ ἢ περιέργοι is used in a good sense, and not intended to imply a pretence of over-refinement, is shown by the parallel passage in the *De Sensu* (i. 4; 436, a, 20). 'It comes also within the province of the natural philosopher (*quâ physiologist*) to treat of the first principles of health and disease. For these are conditions that only affect things that have life. Wherefore most natural philosophers finally touch on questions of therapeutics, while such physicians as pursue their art in a philosophical spirit base their therapeutics on the laws of Nature.'

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